

WOLFF

Mineral Industry
Research Laboratory

HANDBOOK FOR THE ALASKAN PROSPECTOR

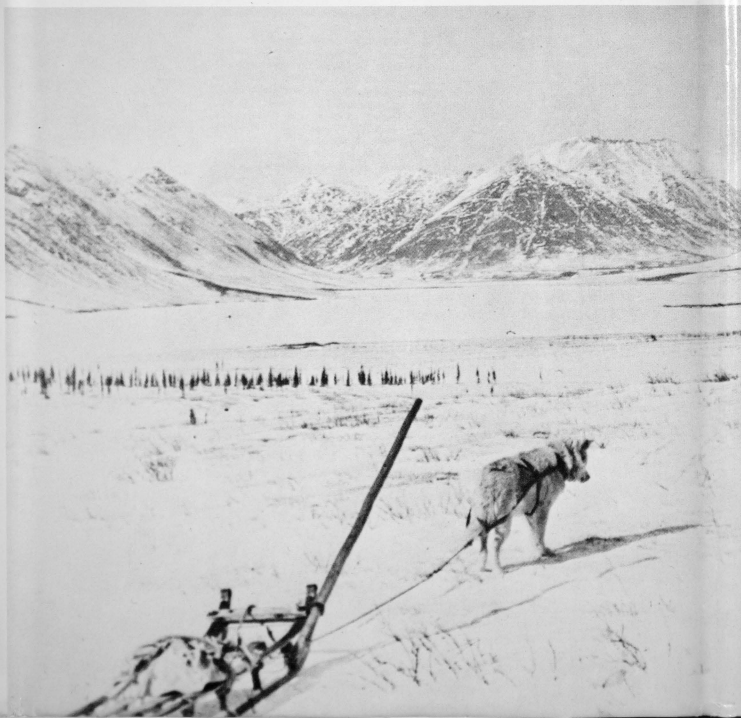
Mineral Industry Research Laboratory

Ernest Wolff

HANDBOOK FOR THE ALASKAN PROSPECTOR

University of
Alaska

College, Alaska



HANDBOOK FOR THE ALASKAN PROSPECTOR

Ernest Wolff

CONTENTS

PART I. GEOLOGY

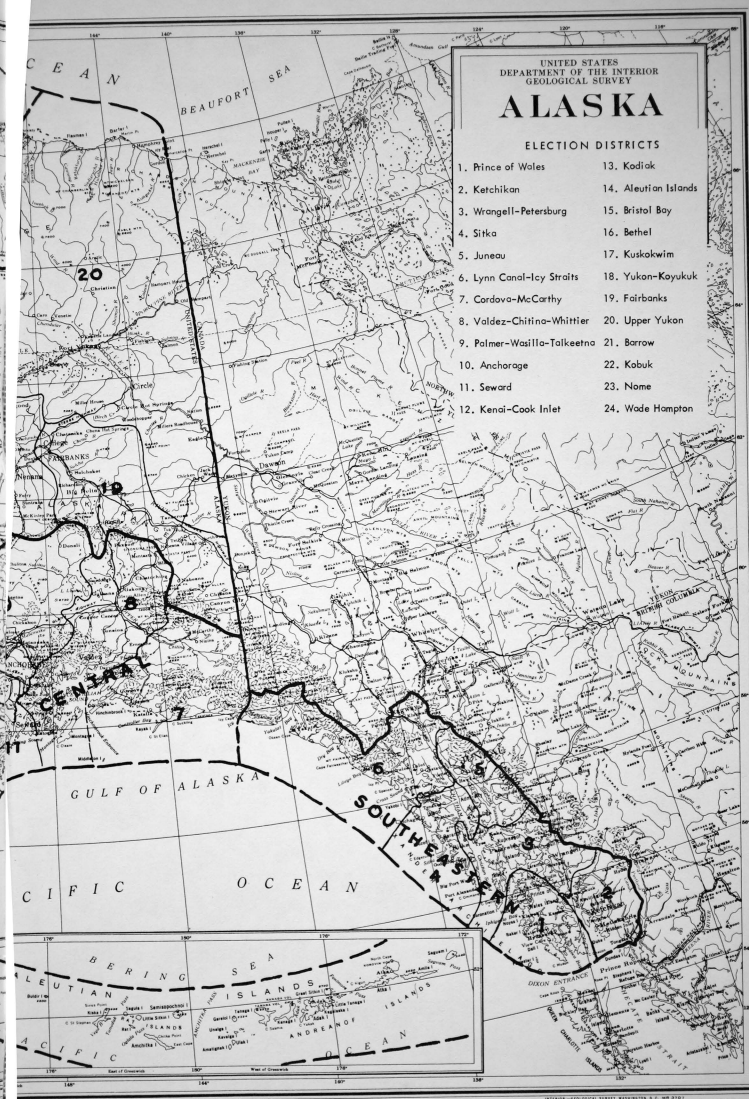
Geology: The Study of Geology, the Constitution of the Earth, Earth Movements. Mineralogy: Properties of Minerals, Identification of Minerals by Chemical methods, Blowpipe and Qualitative tests for Individual Elements, Descriptions of Minerals, Commercial Materials and their Chief Mineral Sources, Determinative Mineralogy. Rocks: Igneous, Sedimentary and Metamorphic Rocks. Structural Geology: Original Structures, Imposed Structures. Historical Geology: The Cretaceous (Pecanibrian) Era, the Phanerozoic Era, Geomorphology: The Fluvial or "Normal" Cycle, The Fluvial Cycle Modified by a Cold Climate, Glaciated Regions, Arid Lands, the Marine Cycle, Underground Solution Processes, Features due to Constructive Forces, Physiographic Provinces. Mineral Deposits: Summary of Events in the Formation of Mineral Deposits, Metallogenetic Epochs, Metallogenetic Provinces, Classification of Mineral Deposits, Controls of Mineralization.

Continued inside back flap

About the Author

Ernest Wolff has been associated with Alaska since 1938. He holds a degree in Mining Engineering from the University of Alaska, and degrees in geology from the University of Oregon. He has taught geology at the University of Alaska and at Colorado State University. Other work besides prospecting includes studies of mining and prospecting methods in Alaska, and geologic work in Alaska, Oregon, and Colorado.





UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

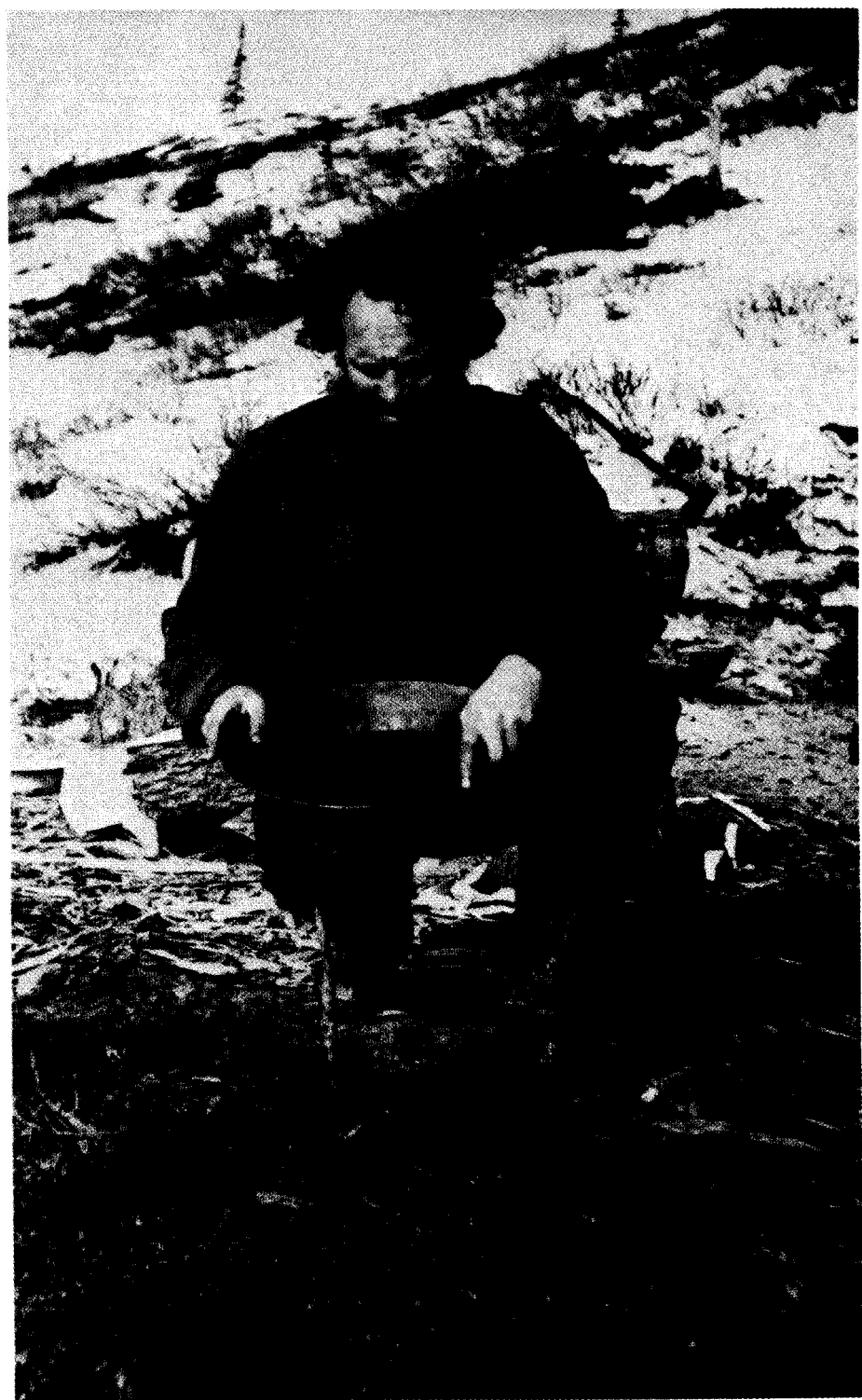
ALASKA

ELECTION DISTRICTS

- | | |
|----------------------------|----------------------|
| 1. Prince of Wales | 13. Kodiak |
| 2. Ketchikan | 14. Aleutian Islands |
| 3. Wrangell-Petersburg | 15. Bristol Bay |
| 4. Sitka | 16. Bethel |
| 5. Juneau | 17. Kuskokwim |
| 6. Lynn Canal-Icy Straits | 18. Yukon-Koyukuk |
| 7. Cordova-McCarthy | 19. Fairbanks |
| 8. Valdez-Chitina-Whittier | 20. Upper Yukon |
| 9. Palmer-Wailla-Talkeetna | 21. Barrow |
| 10. Anchorage | 22. Kobuk |
| 11. Seward | 23. Nome |
| 12. Kenai-Cook Inlet | 24. Wade Hampton |

HANDBOOK
FOR
THE ALASKAN PROSPECTOR

Published by
The Mineral Industry Research Laboratory
University of Alaska
College, Alaska



HANDBOOK FOR THE ALASKAN PROSPECTOR

By

Mineral Industry Research Laboratory

School of Mineral Industry

ERNEST WOLFF

Professor of Mineral Exploration

University of Alaska, Fairbanks

With Contributions by Donald J. Cook, and Mrs. Claude Mathews

Containing Part I, GEOLOGY, and Part II, PROSPECTING TECHNIQUES

Edited by Richard H. Byrns

Formerly, Professor of English, University of Alaska

First Edition

1964

Second Edition

1969

Third Printing

1980

Copyright 1969
UNIVERSITY OF ALASKA
All rights reserved

Printed in the United States of America
By Edwards Brothers, Inc.
Ann Arbor, Michigan

TO THE ALASKAN PROSPECTOR,
PAST, PRESENT,
AND
FUTURE

PREFACE

To grow and prosper, Alaska must develop sources of products which can be exported to pay for the great number of commodities which necessarily must be imported. Because of the long distances which these products must be sent, they are limited to fairly high cost items. A listing of the principal exports of previous years indicates what type of products will bear the high freight cost of exporting. Precious metals, rich base metals, canned salmon, and fur have been our mainstays in the past, but such diverse commodities as coal and potatoes, both of which Alaska is able to produce in large quantities, have not been exported and cannot be at the present time.

Of Alaska's high-value products, fur has lost much of its former value, at least for the present; and the salmon pack has been disastrously low in the past few years. It is hard to tell at the present time exactly how much damage was done to the salmon industry by the recent earthquake on the coast. All responsible Alaskans realize that great efforts must be made to develop the natural resources of Alaska, and to create industries based upon the use of such resources. Such efforts are most likely to meet with success in the near future in those parts of Alaska which enjoy the lowest transportation costs; namely, Southeastern Alaska. In this area pulpwood and low grade base metals might well provide the basis of industries producing for export. The pulpwood already is being produced, and low grade base metal and iron deposits are now under serious investigation. Farther north, in and beyond the Alaska Range, pulpwood obviously drops out of the picture as a potential basis of industry; and base metals, to be considered economically feasible, must be of higher grade than the ores occurring in Southeastern Alaska. In the north, commodities such as gold, platinum, and fur, which require practically no hauling charges, become increasingly important.

More industry can and must develop in Alaska, but in the less hospitable parts only certain types can be established. Alaska has often been compared to Canada; the following quotation from the preface to an early edition of "Prospecting in Canada" by members of the Canadian Geological Survey, 1930, is of interest:

.....though farming was the original pioneer industry, and responsible - after the fur trade - for the settlement of Canada, it has been supplanted in this role by mining and lumbering, and for the reason that civilization in Canada is now moving northward into regions not on the whole well suited for agriculture About one-sixth of the total land area of Canada is arable and much of this is already settled or being settled. About forty per cent is forest-bearing, useful forests extending northward to about latitude 55 degrees in eastern Canada and to the Arctic Circle in the western half. Minerals, on the other hand, are distributed throughout the country in extraordinary variety, and they must constitute the main basis for whatever population and industry develops in the northern half of the country.

It must be remembered that most of Alaska corresponds to "the northern half of the country" as quoted. It cannot be said today that minerals are distributed throughout the country in "extraordinary variety", certainly not in extraordinary quantity; but the point to remember is that when the climate or inaccessibility make the production of agricultural, forest, or fishery products unfeasible, the possibility of industry based on mineral resources still remains.

There is a saying in many languages to the effect that to make a rabbit stew, first catch the rabbit. The mineral industry is the stew; the mineral deposit the rabbit; the man who catches the rabbit is the prospector. Others who come later may determine the size and shape of the rabbit, and still others will make the stew. However, without the hunter, they can do nothing.

At present, many institutions and agencies are helping the prospector and the miner; their functions all differ from each other, but their purposes are the same--the development of a sound mining industry for Alaska. One such institution, the College of Earth Sciences and Min-

eral Industry, University of Alaska, has been producing mining engineers and geologists since its founding. This is its chief method of helping the mining industry. Also for many years, the College has conducted short courses in mining and prospecting at the University and in Alaskan towns wherever the need existed. A third method is through its research activities, started in 1951.

The research program has been purposely weighted toward the side of aiding the Alaskan miner and prospector, because it is believed that, for the beginning at least, this assistance produces the greatest results for the effort expended.

One result of that research program is this Handbook for the Alaskan Prospector, of which this is the first volume, containing Parts I and II. Part I contains chapters on the various branches of geology and mineralogy; Part II is concerned with prospecting methods and related techniques.

It is hoped that this book will be of value to many different classes of men engaged in the search for mineral deposits. These classes might include the experienced practical prospector who would like to learn something of geology; the young geologist who needs information on practical prospecting; the novice who needs a comprehensive reference; and the all around experienced exploration engineer or geologist who might need to refer to some specialized technique, look up a reference in the bibliography, or read a resume of the geology of a particular area. Because this book is aimed at so many different classes, different chapters are written assuming different levels of learning and experience. This, no doubt, will prove troublesome at times, but it is believed to be the best way to insure that the information contained in each chapter will reach with maximum effectiveness the group for whom it is intended.

Many competent books on prospecting, which cover the subject from different viewpoints, are listed in the bibliography, and their reading is recommended highly. The present volume presents some of the same material with emphasis on its application to Alaska, and also presents some uniquely northern techniques, which are not readily available in print.

PREFACE TO SECOND EDITION

Strictly speaking, this is not a second edition, but a second printing, with corrections made where feasible and necessary, and an Addendum (Chapter 20) to describe new developments in several fields taken up in the first edition. In reading the preface to the first edition, the author finds little that he would change. Although the first edition was published in 1964, the writing was done chiefly between 1952 and 1957, and had been essentially completed by 1960. At present (1969) therefore, techniques described are those of ten to fifteen years ago. Many of these techniques of course, are still the best, but others, which are discussed in the appropriate places in the addendum chapter, are being displaced. In addition to techniques, political attitudes towards economics and conservation change, and an attempt is made to describe as well as possible what these attitudes are currently, and to predict what course they may take in the future.

Economics also are changing, and the statement in the first Preface, about not being able to export coal may soon be out of date.

One thing mentioned in the first Preface needs clarification. This book contains Parts I and II, Geology and Prospecting Techniques. Part III was, and is, visualized as a second volume, describing The Geology and Mineral Resources of Alaska.

The first edition was written under a program of "Mining Research" funded by the Legislature through the School of Mines. Since then, this type of research has been taken over by an organization within the structure of the College, The Mineral Industry Research Laboratory. It is this laboratory which is sponsoring this second edition, and its name appears on the title page.

A book of such scope as this one is necessarily a compilation of the work of others. At the end of each chapter appears a list of the principal publications referred to, and other publications appear in the general bibliography near the end of the book. Acknowledgments are given in the text for the use of direct quotations or specially organized material; here is acknowledged the debt to all who have contributed to the great pool of printed knowledge without which this book could not have been compiled.

There are, in addition, others who have contributed in other ways. Earl H. Beistline, Dean, College of Earth Sciences and Mineral Industry, University of Alaska, conceived the idea of the book in the first place, administered the work and provided solutions for the hundreds of problems which arose during the writing. The following have acted as technical editors for one or more chapters: Bruce I. Thomas, U. S. Bureau of Mines, College, Alaska; Harry B. Groom, Jr. and Stanislaw Poborski, both formerly with the Geology Department, University of Alaska; Troy L. Pewe, U. S. Geological Survey and the University of Alaska; Robert H. Saunders, Alaska Division of Mines and Minerals, College, Alaska; Wallace B. Murcray, and Dan C. Wilder of the Geophysical Institute, University of Alaska; Research Department of E.I. du Pont de Nemours and Co.; Nalin R. Mukherjee, formerly in the Department of Mining and Metallurgy, University of Alaska; Leo Mark Anthony and Edward T. Barnes, Jr., both with or formerly with the Mining Extension Department of the University of Alaska; Raymond L. Smith, Michigan College of Mining and Technology; Russell A. Paige, U. S. Geological Survey, College, Alaska; and William Benda, U. S. Geological Survey, who helped with much of the determinative table of Chapter Two. Mrs. Claude Matthews wrote much of Chapter Three. Mr. Charles Keim, Assistant Professor of Journalism and Director of Information, University of Alaska, provided valuable assistance in problems of format and illustration.

It is impossible to name everyone who contributed information for Part II of this book, but the following Alaskans deserve special mention: Ted C. Matthews, engineer; James A. Williams, engineer; E. J. Ulen, wireless operator and miner; Hugh J. Matheson, Jr., engineer and miner; Clyde Wahrhaftig, geologist; Jack Newbauer, miner; the late Frank Yasuda, prospector and merchant; Val L. Freeman, geologist; Obren Stannich, miner; Alfred W. Amero, miner; Ellis Anderson, miner; Joseph Regnier, driller; John R. Hoskins, engineer; Wayne Adney, prospector and trapper; Mark Christensen, geologist; Gordon Herreid, geologist; the late John McCall, geologist and glaciologist; Sammy Pingalo, trapper and prospector; David Hopkins, geologist; James C. Crawford, engineer; H. R. Joesting, geophysicist, and finally the late Dennis J. O'Keefe, prospector, whose picture appears as the frontispiece of this book.

To my wife, who has read and reread, typed and retyped the manuscript goes special thanks; and to Dorothy Creely, Harriet Napieciniski, and Janet Reidel, who made the final copy possible also go many thanks.

The drawings for this book have been made by Mary Ann Kegler, Jean Nichols, Albert W. Balvin, Harry B. Groom, Jr., and the chief author. Photographs are by the author unless otherwise stated. Most of the aerial photographs were made possible by the courtesy of the U. S. Air Force.

It remains only to state that by acknowledging the debt to an individual does not imply that the individual agrees with all the statements contained in this book. Many indeed, of those herein mentioned, did not even know that this book was in preparation. Any shortcomings that exist are the responsibility of the chief author.

E. W.

TABLE OF CONTENTS

Chapter	Page
PART I. GEOLOGY	
Preface	ix
Acknowledgments	xi
1. INTRODUCTION TO GEOLOGY; STRUCTURE OF THE EARTH The Study of Geology; the Constitution of the Earth; Earth Movements	1
2. MINERALOGY Introduction; Properties of Minerals; Identification of Minerals by Chemical methods; Blowpipe and Qualitative Tests for Individual Elements; Descriptions of Minerals; Commercial materials and their chief Mineral Sources; Determinative Mineralogy	3
3. THE STUDY OF ROCKS Introduction; Igneous Rocks; Sedimentary Rocks; Metamorphic Rocks; Conclusion	61
4. STRUCTURAL GEOLOGY Original structures; Imposed Structures	76
5. HISTORICAL GEOLOGY Introduction; the Cryptozoic (Precambrian) Eon; The Phanerozoic Eon	82
6. SURFACE FEATURES OF THE LAND, GEOMORPHOLOGY Introduction; The Fluvial or "Normal" Cycle; The Fluvial Cycle Modified by a Cold Climate; Glaciated Regions; Arid Lands; The Marine Cycle; Underground Solution Processes; Features due to Constructional Forces; Physiographic Provinces	102
7. MINERAL DEPOSITS Introduction; Brief Summary of Events in Formation; Metallogenetic Epochs; Metallogenetic Provinces; Classification of Mineral deposits; Controls of Mineralization	139
PART II. PROSPECTING	
8. BACKGROUND The Prospector; Analysis of Present Status of Mining and Prospecting in Alaska; Brief History	171
9. GENERAL PROSPECTING Definitions; Preliminary to Field Work; Reconnaissance	180
10. PROSPECTING AND EXPLORATION OF LODES Prospecting; Exploration; Summary of Surface Methods; Underground Openings; Development and Exploitation; Sampling Procedures and Calculating Results; Prospecting and Exploring with Bore Holes	184
11. DIAMOND DRILLING The Diamond Drill; Casing the Diamond Drill Hole; Core Drilling	201

Chapter	Page
12. PROSPECTING AND EXPLORATION OF PLACER DEPOSITS General; Opencutting; Crosscutting the Creek	207
13. SINKING PLACER PROSPECT SHAFTS Sinking shafts in Frozen Ground; Sinking shafts in Thawed Ground	215
14. DRILLING PLACER DEPOSITS Introduction; Equipment; Process of Drilling; Keeping Records and Handling Samples; Calculating Drill Holes; Evaluating the Ground	236
15. GEOPHYSICAL, GEOCHEMICAL, AND MINERALOGICAL PROSPECTING Geophysical Methods; Geochemical Methods; Mineralogical Prospecting	266
16. AUXILIARY TECHNIQUES Surveying and Mapping; Reading Geologic Maps and Aerial Photographs; Drilling Rock for Blasting; Use of Explosives; Blacksmithing; Use of the Pan and Rocker; Handling Gold; How to Build Various Appliances Used in Prospecting	290
17. TRANSPORTATION; CLOTHING; SHELTER; FOOD; TECHNIQUES AND EQUIPMENT USED IN CAMP LIFE Transportation; Communications; Shelter; Food; Clothing	321
18. ELEMENTS OF MINING LAW; STAKING CLAIMS Introduction; History; Laws Pertaining to both Lode and Placer; Lodes; Placers; Tunnel Sites; Prospecting Sites; Millsites; Water Rights; Liens; Grubstake Agreements; Patenting; Leasing; Licenses and Taxes; Forms; Conclusions	343
19. GEOGRAPHY OF ALASKA Legal Subdivisions; Subdivisions Based on Geology and Geography; Broad Geographical Features; United States Geological Survey Subdivisions; Chief Transportation and Communication Routes	358
APPENDIX	371
I. Sources of Information and Aid to Prospectors	371
II. Weights, Measure, Sizes	374
III. Short Glossary of Alaskan Terms	377
BIBLIOGRAPHY Arrangement and Scope of Bibliography; Publications of the United States Geological Survey; United States Bureau of Mines; Bureau of Land Management; University of Alaska; Territorial and State; General	379
20. ADDENDUM Introduction; Notes on Chapters 1, 5, 8, 9, 12, 13, 14, 15, 16, 17, 18, 19	407
ADDITIONS TO BIBLIOGRAPHY	424
INDEX	437

LIST OF ILLUSTRATIONS

Frontispiece		
Chapter 2		
		Page
Fig. 2-1	Six crystallographic systems	6
2-2	Luminous flame	11
2-3	Blowpipe flame	11
2-4	Heating Assay on charcoal support (in oxidizing flame)	11
2-5	Open tube	15
2-6	Closed tube	16
Chapter 3		
Fig. 3-1	Extrusive and intrusive rock forms	62
3-2	Combinations of Minerals that compose Igneous Rocks	68
3-3	Cycle of rock formation	75
Chapter 4		
Fig. 4-1	Components of folds	77
4-2	Plunging folds	78
4-3	An oblique slip normal fault	79
4-4	A faulted coal seam - photo	81
Chapter 5		
5-1	Unconformity representing perhaps one billion years	86
Chapter 6		
Fig. 6-1	Meandering stream and oxbow lakes - photo	106
6-2	Stages in the development of streams	107
6-3	Stream sections	107
6-4	A stream capture in the Brooks Range	108
6-5	Stream patterns	109
6-6	Permafrost zones of Alaska	113
6-7	Features of Permafrost	114
6-8	Ice wedge	114
6-9	Ice wedge polygons	114
6-10	Solifluction	115
6-11	Approximate extent of Pleistocene glaciation in Alaska	117
6-12	Glaciated U-shaped valley in the Alaska Range-photo	118
6-13	A tarn in Alaska	120
6-14	Horns and knife edge ridges being formed by cirque glaciers in Alaska - photo	120
6-15	Valley glaciers - photo	121
6-16	Knob and kettle topography - photo	123
6-17	Relations of placers to glaciation on Little Squaw Creek Chandalar District, Alaska	126
6-18	Shore profiles of submergent and emergent shorelines	130
Chapter 7		
Fig. 7-1	Layers of segregated chromite ore of magmatic concentration origin	145
7-2	Contact metasomatic deposit	146
7-3	Cavity fillings	149
7-4	Cross-sections of types of placers	158
7-5	Idealized zones of oxidation and secondary sulfide enrichment	159
7-6	Idealized relationship of mineral deposits to batholith	165

Chapter 8		
Fig. 8-1	A veteran of the Kobuk stampede still looks forward to a big strike - photo	175
Chapter 9		
Fig. 9-1	Groundsluicing a preliminary drain to get below loose gravel - photo	183
Chapter 10		
Fig. 10-1	Brunton compass set up for tracing veins - photo	185
10-2	Relationship of float to vein on hillside	187
10-3	Locating lode by panning	187
10-4	Conditions under which shaft sinking or drifting might be preferable	189
10-5	Arrangement of blast holes for shaft sinking	190
10-6	Arrangement of blast holes for drifting	191
10-7	Drift timbering	193
10-8	Section of vein showing blocks of ore	197
10-9	Possible diamond drill holes	199
Chapter 11		
Fig. 11-1	Small "packsack" diamond drill in operation - photo	202
Chapter 12		
Fig. 12-1	Log dam with automatic gate	209
12-2	Longitudinal section along creek being groundsluiced	210
12-3	Groundsluicing - photo	212
Chapter 13		
Fig. 13-1	Wood and steel windlass buckets	216
13-2	Self dumping bucket arrangement	216
13-3	Ladders	217
13-4	Penberthy injector	219
13-5	Boiler handpump	219
13-6	Doghouse boiler showing piping	220
13-7	Preparing to build a fire in the shaft - photo	221
13-8	Prospect boiler in operation - photo	223
13-9	Placer prospect shaft	224
13-10	Shaft timbering cribbing and sets	225
13-11	Method of sealing a shaft in permafrost	227
13-12	Measurements to illustrate calculations of tenor of frozen ground	227
13-13	Working placer ground on Porcupine Creek by utilizing winter freezing	229
13-14	Caisson and hoist	230
13-15	Arrangement of caisson equipment	232
13-16	Caisson log	233
Chapter 14		
Fig. 14-1	Airplane drill in operation - photo	238
14-2	String of tools and casing	240
14-3	Drill tools being assembled	240
14-4	Dippers	243
14-5	Fairbanks drill in operation - photo	244
14-6	Oil drum heater	249
14-7	Drill log, thawed hole	252
14-8	Drill log, frozen hole	254
14-9	Relationship of pours to top and bottom of pay horizon	255
14-10	Relationship between volumes of pours and volumes of one foot intervals in drill hole in frozen ground	256
14-11	Block of ground laid out for line method	259
14-12	Block of ground laid out for three point triangle method	260
14-13	Two point triangle	262
14-14	Block of ground laid out for diamond method	263
Chapter 15		
15-1	Subtracting effect of regional changes from gravimetric results	267
15-2	Correcting magnetometric values for diurnal variation	271

Chapter 15 continued

Fig. 15-3	Natural earth currents around a sulfide body	272
15-4	Three electrode resistivity configuration	273
15-5	Percent U_2O_8 against counts per minute	277
15-6	Prospect delineated by soil samples, and distribution of water samples	284
15-7	Two Distributive provinces	286

Chapter 16

Fig. 16-1	Plotting primary triangulation net	291
16-2	Levelling techniques	293
16-3	Geologic map symbols	295
16-4	Geologic map and section	296
16-5	Drill hole profile	297
16-6	Graphical method of determining difference in elevation	298
16-7	Ways of making primers	305
16-8	Cutting edges of bits	311
16-9	Clean up paddle	315
16-10	Windlass	317
16-11	Rocker	318
16-12	Sluice box and riffles	319

Chapter 17

Fig. 17-1	Snowshoeing an airstrip - photo	322
17-2	Basket sled and Yukon sled with dog work harness	324
17-3	Boiler ready for hauling - photo	325
17-4	Freighting with sled - photo	326
17-5	Three snowshoe hitches	327
17-6	Improvised packsack	328
17-7	Dog pack	328
17-8	Cache and tent - photo	333
17-9	Saw buck and buzz saw	334
17-10	Windchill nomogram	341

Chapter 18

Fig. 18-1	Lode claim	348
18-2	Extralateral rights	349
18-3	Placer claims	350

Chapter 20

Fig. 20-1	Early and Late Geosynclinal Stage	409
20-2	Parallel Line Method of Dip Angle Determination	414

PART ONE

GEOLOGY

Chapter 1

INTRODUCTION

THE STUDY OF GEOLOGY

A working knowledge of geology must be mastered by the prospector before he can make an intelligent search for minerals; Part 1 of this book endeavors to present the fundamentals of this science. It is suggested that Part 1 be supplemented by any recent book on general geology.

Although innumerable special branches of the science might be listed separately, for the purpose of this book geology is divided into the following:

- (1) Mineralogy - The study of minerals.
- (2) Petrology - The study of rocks.
- (3) Structural geology - The study of the structural forms of rocks.
- (4) Historical geology - The study of events which have resulted in our earth as it is - its rocks, soils, land forms, etc. Special subjects closely associated with historical geology are stratigraphy, the study of the stratified layers of sediments; and paleontology, the study of fossil organisms in rocks.
- (5) Geomorphology or physiography - The study of the surface forms of the earth and their causes.
- (6) Economic geology (Ore deposits or mineral deposits) - The study of the earth materials useful to man.

Other branches of geology are specialized studies of one or more of those listed.

THE CONSTITUTION OF THE EARTH

Early observers believed the interior of the earth to be molten, because they had observed flowing lava and the rocks which had obviously solidified from this molten state. It is now known, from its behavior in response to the attraction of other bodies, particularly the moon, that the earth is rigid, at least through its outer 1800 miles. The current belief is that the great pressure exerted by the crust, as the earth's outer few miles is called, is responsible for keeping the interior of the earth solid.

The average specific gravity of the earth, i.e., the weight of a given volume of material divided by the weight of an equal volume of water, is known to be 5.52. The average specific gravity of the rocks in the earth's crust is about 3.0. Therefore, the material below the crust must have a specific gravity higher than 5.52 in order to balance the lighter rocks of the crust. A current explanation that fits the observed data is as follows: that part, from the base of the crust to a depth of about 1800 miles, is known as the mantle. The upper part of the mantle consists of dark, heavy, ultra basic rock, such as peridotite (See Chapter 3). The lower part may have an admixture of sulfides or oxides, or it may consist of a different form of the same rock as the upper part.

Between the mantle and the overlying crust is a sharp break called the Mohorovicic discontinuity. At the base of the mantle is another break, and below this is the core, supposedly composed of a nickel-iron alloy. The outer part of the core, at least, acts like a liquid, while the inner part may be solid again.

It is known from observations made in deep drill holes and mines that temperature increases with depth, although at a decreasing rate. Projecting the temperature gradient downward, it is seen that temperatures are great enough to melt rock at depths of a few tens of miles; only the great pressure keeps the materials solid. At these extreme temperatures and pressures, rock flows like a plastic; and the lighter rocks of the earth's surface are believed to be floating on the underlying semi solid material.

Most of the earth's crust is composed of dark basic rocks, about 10% heavier than the light colored rocks. The light colored rocks, where they occur in great masses, as they do in the continents, will therefore rise until they are floating in equilibrium with the dark, heavy rocks. Ideally, 10% of their mass protrudes above the underlying basic rocks. High reaching mountains, therefore, are the tops of thick portions of the acidic rocks floating on the plastic interior rather than dead loads resting on the earth's rigid crust. This theory of floating equilibrium is called isostasy meaning equal standing. If it is valid, no large masses of granitic rock lie under the deep seas, a fact borne out by seismic measurements and direct observation of the materials of islands which rise from the deep sea floors. Basic lavas on the continents were forced up along great fissures extending downward through the acidic continental

rocks. Chains of volcanoes indicate the location of these fissures.

Besides the rugged mountains, all continents have non-mountainous regions where the lighter continental type rocks are thinner than they are in the mountains. The continental shelves are the extensions into the seas of the continental masses. At the edges of the shelves the bottom drops off sharply to the ocean basins. Thus the edges of the continental shelves, not the shorelines, represent the true limits of the continents.

EARTH MOVEMENTS

In the three and a half to five billion years the earth has been in existence, its entire surface should theoretically have been reduced, by erosion, to sea level, yet mountains which reach miles above sea level, and submarine trenches extending miles below the level of the sea, still exist. The theory of isostasy explains why. As a mountain mass is worn down, it floats higher and higher. Eventually, of course, it can disappear completely, but only after miles of materials have eroded away; by that time lateral movement (see below) may thicken a portion of the earth's crust to form mountains again.

Another set of earth movements for which there is yet no satisfactory explanation are the great lateral thrusts that play an important part in mountain building. Almost all of the great mountain ranges of the world have been subjected to extreme lateral pressure which has crushed, folded, and ruptured the earth, sometimes forcing one block over another for a distance of 25 miles. These pressures have been explained by various theories, each of which has its strong and weak points; they may be caused by convection currents within the plastic earth, by wrinkling due to shrinking of a contracting earth, or by the so-called continental drift, a theory which maintains that the continents are slowly moving, thrusting and crushing rocks in their path.

If, as is believed, the continents are thin layers of granitic rocks ("granitic," "acidic," and "light colored" all refer to the same type), it is only through the lateral movements that they are preserved at all and not eventually worn down to sea level. For, as the products of erosion are removed from the continents, the light weight material of the continental mass becomes thinner and thinner. Uplift of the mountains to maintain isostatic balance eventually ceases because no more light material is available beneath the highlands. Horizontal pressures, however, whatever their origin, operate to squeeze the continents together, thereby thickening this light material and preserving it.

All of the movements of the crust which change the relative positions of different points or result in deformation are known as diastrophism (from the Greek "general turning"). When diastrophism results in mountain building, it is known as orogeny; when it results in the broad uplift of level plains or plateaus, it is known as epeirogeny.

Whatever their cause, the lateral movements have their greatest effects in certain areas on the earth where they crumple and rupture the crust. These areas become the mountainous areas. This crumpling is believed to set off a chain of events which may culminate in the deposition of valuable ore deposits. The relief of pressure due to the deformation of the crust allows the underlying hot plastic rock to liquify and to move toward the area of less pressure. (Many mountain chains have igneous rock cores). The cooling igneous rock masses in an area are believed to provide the material of many mineral deposits. (See Chapter 7.)

From the foregoing it is seen that there is a continual struggle between the forces tending to wear down the land and fill in the ocean basins and those tending to build up the continents and deepen the oceans. This continual struggle has produced the land surface as it is known today.

References

- Emmons, Thiel, Stauffer, Allison, 1955, *Geology*, 4th Ed: McGraw-Hill, New York
 Gilluly, Waters, Woodford, 1959, *Principles of Geology*, 2nd Ed: W.H. Freeman and Company

Chapter 2

MINERALOGY

INTRODUCTION

To understand what a mineral is, an understanding of the constituents of matter is necessary. First, an element is the fundamental unit of matter that can be produced by ordinary chemical means. Ninety two elements occur naturally, and several more have been created by man by the addition of even more fundamental units to already existing elements. These latter elements, however, require more than ordinary chemical means to produce them, and therefore are of little value in this discussion. Of these ninety two elements, only a few, which combine with other elements only with difficulty, are found alone in nature, and of these, some are gases, and do not concern the prospector. An example of a naturally occurring solid element is gold; of an artificially separated element, magnesium metal; of a naturally occurring gaseous element, nitrogen (in the air).

Because these elements are the fundamental units from which the other materials of the earth are built they have been assigned symbols. The symbols of the three examples are "Au," gold; "Mg," magnesium; and "N₂," nitrogen.

Compounds are combinations of elements held together by chemical forces. Most elements have strong affinities for certain other elements, and by combining with them they form compounds. Oxygen, for example, combines with many elements to form oxides, and the familiar red color of rust is the result of oxygen combining with iron. It is not surprising therefore, that most of the substances found in nature are made up of compounds. Since compounds are made up of elements in fixed proportions they can be expressed in elemental symbols as formulas; e.g. water, hydrogen oxide, H₂O.

The atom is the smallest unit of an element which still has the same composition as the element. If an element is broken down into units smaller than an atom, something different from the element must be the result. These are the more fundamental particles previously mentioned. The molecule is the smallest unit of a compound which still has the same composition as the compound. If a compound is broken into units smaller than a molecule, the resultant parts will be atoms of the elements making up the compound.

Compounds may be organic or inorganic. The organic compounds are those composed in part of carbon, and are usually associated with living organisms. Tar is an example of an organic compound; salt is an example of an inorganic compound.

A crystal is the fixed shape which an element or compound assumes upon solidifying from a melt or a solution. There are six crystal systems, with 32 crystal classes distributed between them. Substances may form into large or small, perfect or imperfect, crystals. Substances which do not form crystals are amorphous. Substances composed of extremely fine crystals are cryptocrystalline (hidden crystalline). Crystal outline is an outward reflection of an orderly internal arrangements of atoms and molecules, and crystallinity is a guarantee of homogeneity and comparative purity.

With the aid of the above terms, a definition of a mineral can be set up. A mineral is a naturally occurring substance of definite composition, and with few exceptions, a definite crystalline structure. Thus it can be said that minerals are naturally occurring elements or compounds. A few are amorphous; almost all are inorganic. Some definitions limit minerals to inorganic substances. However, asphalt, amber, and a few others are sometimes classed as organic minerals. Other definitions limit minerals to crystalline substances, and classify naturally occurring amorphous substances as mineraloids.

Almost all of the substances with which the prospector deals: rocks, soils and agglomerations of metallic minerals, are made up of minerals. Therefore the prospector must be familiar with minerals.

Over 1500 known mineral species exist. Very few books describe them all, because most of these minerals are rare and of interest only to specialists. Books on mineralogy usually describe a few hundred minerals; in this book about 110 are described. They have been chosen for either of two reasons: They are (1) minerals which are found in almost every locality, or (2) they are important economically. The first are mostly rock forming minerals; the second, economic minerals.

There are several branches to the study of mineralogy, or ways in which the subject may be considered. The primary aim of this chapter is to teach the rapid and accurate identification

of certain minerals and the economic importance of each to the prospector. To accomplish this aim the chapter is divided into (1) this introductory statement, (2) a description of the properties by which minerals may be identified, (3) a description of the chemical tests used in identifying minerals, (4) a complete listing of the minerals, with a description of each in terms of association and physical and chemical properties, (5) a listing of the chemical tests for individual elements, (6) a listing of commercial materials and their chief mineral sources, and (7) tables whereby a mineral may be identified by a systematic procedure (determinative tables).

The following minerals are to be considered:

Actinolite (see Asbestos)	Halite
Anglesite	Hematite
Anhydrite	Hemimorphite
Apatite	Hornblende
Argentite	Huebnerite (see Wolframite)
Arsenic	
Arsenopyrite	Ilmenite
Asbestos Group	
Augite	Jade
Azurite	Jamesonite
Barite	Kaolinite
Bauxite	
Beryl	Leucite
Biotite	Limonite
Bismuth	
Bismuthinite	Magnesite
Bornite	Magnetic
	Malachite
Calcite	Manganite
Carnotite	Marcasite
Cassiterite	Mica Group
Celestite	Molybdenite
Cerargyrite	Monazite
Cerrussite	Muscovite
Cervantite	
Chalcedony	Nepheline
Chalcocite	Niccolite
Chalcopyrite	
Chlorite	Olivine
Chromite	Opal
Chrysocolla	Orpiment
Cinnabar	
Cobaltite	Pentlandite
Columbite, Tantalite	Phlogopite
Copper	Pitchblende
Corundum	Platinum
Covellite	Proustite
Cryolite	Psilomelane
Cuprite	Pyargyrite
	Pyrite
Dolomite	Pyrolusite
	Pyrrhotite
Enargite	
Epidote	Quartz
Feldspar Group { Orthoclase	Realgar
Microcline	Rhodochrosite
Plagioclase	Rhodonite
Ferberite (see Wolframite)	Rutile
Fluorite	
Franklinite	
	Scheelite
Galena	Serpentine
Garnet Group	Siderite
Gold	Sillimanite Group
Graphite	Silver
Gypsum	Skutterudite

Smithsonite	Titanite
Sodalite	Tourmaline
Sphalerite	Tremolite (see Asbestos)
Spodumene	
Stannite	Uraninite (see Pitchblende)
Staurolite	Vanadinite
Stibnite	
Strontianite	Wolframite
Sulfur	Wulfenite
Sylvite	
Talc	Zeolite Group
Tantalite (see Columbite)	Zincite
Telluride	Zircon
Tetrahedrite	

PROPERTIES OF MINERALS

Just as members of the animal or vegetable kingdoms may be recognized by certain characteristic properties, so may minerals be identified by their characteristic properties. The following describes some of the different properties used in identifying minerals.

Crystal Form

The crystal class to which a particular mineral belongs is determined by the amount of symmetry the mineral exhibits. The elements of symmetry are: (1) An axis about which the crystal may be rotated, repeating itself in appearance two or more times during the rotation. (2) A plane through the center of the crystal, dividing the crystal into halves, each side of which is a mirror image of the other. (3) A center of symmetry through which any line will meet like points at opposite sides of the crystal and at equal distances from the center. This is known as inversion. (4) An Axis of rotary inversion, combining rotation about an axis with inversion about a center.

The crystal classes are determined by how many of the elements of symmetry are possessed, how many times the crystal repeats itself during each symmetry operation, and in how many positions symmetry operations may be performed. Although there are 32 crystal classes, most of the common minerals crystallize into ten or twelve of them, which are therefore more important.

Each of the classes belongs to one of the six systems. The systems are defined in terms of crystallographic axes which are imaginary axes through the crystal center; all but the hexagonal system possess three crystallographic axes. (The hexagonal system possesses four axes). The crystal systems and their axes are as follows:

- (1) Isometric system, three mutually perpendicular equal axes.
 - (2) Hexagonal system, three equal axes in a plane, intersecting at angles of 120° , and a fourth of different length passing through their intersection perpendicular to the plane of the other three.
 - (3) Tetragonal system, three mutually perpendicular axes, two of which are equal, and the third of different length.
 - (4) Orthorhombic system, three mutually perpendicular unequal axes.
 - (5) Monoclinic system, three unequal axes, one of which is inclined to the other two at an oblique angle, with two being perpendicular to each other.
 - (6) Triclinic system, three unequal axes, all intersecting at oblique angles.
- These are illustrated in Fig. 2-1.

Crystals in nature seldom are complete and undeformed, but it is often possible to see a portion of a crystal, reconstruct the symmetry, and identify the crystal thereby. The crystallographic characteristics of a mineral which will be used in identifying minerals are as follows:

HABIT - The common and characteristic form or combination of forms in which the mineral crystallizes is the habit. A mineral may crystallize in several forms, but one of them is most common; hence it is the habit of the mineral. It is the general appearance due to form, such as cubical, fibrous, tabular, columnar, etc. The following habits are common:

1. Acicular - Needlelike
2. Capillary and filiform - Hairlike
3. Bladed - Single or aggregates of flattened blades
4. Dendritic - Plantlike branches
5. Reticulated - Latticelike groups of slender crystals
6. Divergent or radiated - Radiating
7. Drusy - Surface covered with small crystals
8. Columnar - Elongated column like

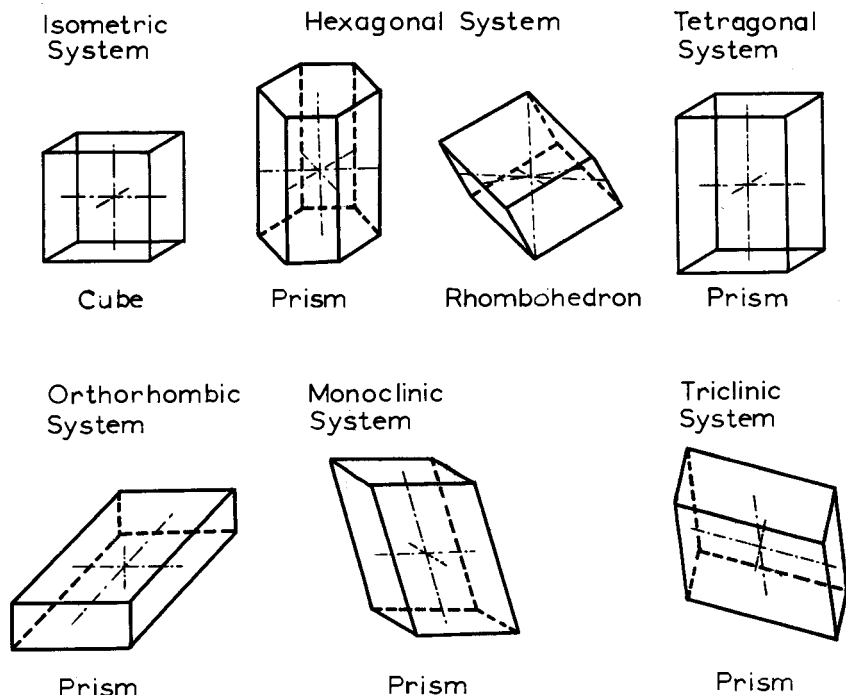


Fig. 2-1. - Six Crystallographic Systems

9. Fibrous - Fibrous aggregates
10. Botryoidal - Like a bunch of grapes
11. Mammillary - Rounded masses
12. Colloform - General term for rounded masses
13. Foliated - Separating into plates or leaves
14. Micaceous - Splitting into extremely thin sheets
15. Lamellar or tabular - Flat plates superimposed on each other
16. Granular - An aggregate of grains
17. Stalactitic - Pendant cones
18. Concentric - Concentric spherical layers
19. Pisolitic - Rounded masses about the size of peas
20. Oolitic - Like fish roe
21. Banded - In narrow bands
22. Amygdaloidal - Containing almond shaped nodules
23. Massive - Compact, irregular, formless.

TWINNING - When two or more crystals grow together so that (1) one appears as a reflection of the other, (2) one appears to have been rotated with respect to another, or (3) they are symmetrical about a point, they are said to be twinned. Certain minerals tend to exist as twinned crystals, which then become an important aid to identification.

PSEUDOMORPHS - A pseudomorph is literally a "false shape," and occurs when one mineral replaces another, volume for volume. The result is a mineral having the crystal shape of another.

POLYMORPHISM - Polymorphism (many shapes) is the crystallizing of the same chemical material into more than one mineral. The minerals are identical in chemical composition, yet have entirely different crystal structures.

Physical And Chemical Properties Of Minerals

Besides the outward form of the mineral, just considered, numerous other properties can

be used for identification.

PROPERTIES DEPENDENT UPON LIGHT - There are a number of properties which depend upon light.

Color - The color of a mineral is one of the first physical properties observed. Some minerals have a fairly constant color; the color of others may vary greatly due to the presence of inclusions or other impurities. Color is more constant and dependable in metallic minerals than in non-metallics. Some minerals show different colors as the specimen is slowly turned; this phenomenon is called change of color.

After certain minerals have been exposed to air, the color of exposed portions differs distinctly from that of the freshly fractured surfaces; this change is termed **tarnish**.

Some minerals show a play of bright colors called **iridescence**, due to a thin coating or film on the surface of the specimen (often the case with limonite).

Streak - Streak is the color of the fine powder of a mineral and is a valuable property used in the determination of minerals, because although the color may vary greatly, the streak is usually fairly constant. The color of the streak may be determined by crushing, filing, or scratching, but the usual and most satisfactory method is to rub the mineral on a piece of white, unglazed porcelain, called the **streak plate**. The streak plate cannot be used with minerals with a hardness of seven or more, because these minerals are harder than the plate. If no streak plate is available, small fragments should be crushed to a fine powder and examined for color against a light colored background. When using the streak plate, the prospector should make very short streaks to avoid a confusing jumble of marks. Streak plates should be washed occasionally.

Luster - The luster of a mineral is the appearance of the mineral's surface in reflected light.

The two main types of luster are **metallic** and **nonmetallic**. Metallic luster is shown by metals and minerals of a metallic appearance; these minerals are usually opaque or nearly so, and heavy. The common minerals pyrite and galena possess metallic luster.

All other kinds of luster are referred to as being **nonmetallic**. Submetallic luster is intermediate between metallic and nonmetallic. Some nonmetallic lusters are: **adamantine**, the exceedingly brilliant luster of minerals such as diamond; **dull** or **earthy**, not bright or shiny, good examples are chalk and kaolin; **greasy**, the appearance of an oiled surface; **resinous**, the luster or appearance of resin, well shown by sphalerite; **silky**, the result of a fibrous structure and well shown by fibrous gypsum and asbestos; and **vitreous**, the luster of glass or quartz.

Luminescence - When heated or exposed, in the dark, to ultraviolet rays, some minerals glow or become **luminescent**. A substance is said to **fluoresce** if it is luminescent during the period of exposure to ultraviolet light, and to **phosphoresce** if the luminescence continues after the source is removed.

Transparency, translucency, opaqueness - Transparency is the ability of a mineral to transmit light, and substances through which objects can be easily and distinctly seen are said to be transparent. When some light passes through the substance and objects are seen only indistinctly, the mineral is **translucent**. A thin edge of the mineral is used to determine if it is translucent. Substances are **opaque** when no light is transmitted even through thin edges or layers.

HARDNESS - The resistance offered by a mineral to abrasion or scratching is termed **hardness**.

The scale of hardness is based upon ten common minerals arranged in order of increasing hardness, as follows:

- | | |
|--------------|--------------|
| (1) Talc | (6) Feldspar |
| (2) Gypsum | (7) Quartz |
| (3) Calcite | (8) Topaz |
| (4) Fluorite | (9) Corundum |
| (5) Apatite | (10) Diamond |

Values for approximate hardness:

- Finger nail - up to 2.5
- Copper coin - up to 3
- Knife blade - up to 5.5
- Window glass - 5.5
- Steel file - 6 to 7

As the hardness of the minerals falls between three and seven, fairly exact determinations of hardness can be made with four or five minerals, a knife, and the fingernail. Hardness pencils, with points of standard hardness can also be obtained. Great care must be exercised in measuring hardness to see that impurities do not give an inaccurate

impression. Earthy minerals give too low a hardness value. In the determinative tables in this chapter, S (soft) indicates the mineral can be scratched with the fingernail; H (hard) indicates the mineral can be scratched with a knife but not by the fingernail, and V (very hard) indicates that the mineral cannot be scratched with a knife.

SPECIFIC GRAVITY - The specific gravity of a substance is its weight compared with the weight of an equal volume of water. For instance, the specific gravity of quartz is 2.65, meaning that a piece of quartz is 2.65 heavier than an equal volume of water. In the laboratory the average specific gravity of a mineral can be determined with a Jolly Balance. The most practical way of determining average specific gravity in the field, however, is by continued practice of lifting and weighing minerals in the hand. The average specific gravity of rock forming minerals is 2.65 to 2.75. Comparison of an unknown mineral with a known mineral such as quartz (specific gravity, 2.65), sphalerite (specific gravity 3.5 to 4), pyrite (specific gravity 4.9 to 5), galena (specific gravity 7.4 to 7.6), etc., is helpful. The pieces chosen should be about the same size.

One very noticeable characteristic of most ore minerals is that they are heavier than rock minerals. If an especially heavy mineral is discovered, even though it has a nonmetallic luster, it is always a good policy to identify it in case it is of economic value.

CLEAVAGE - Cleavage is the property of splitting or separating easily along definite planes. It is frequently very conspicuous and highly characteristic. A mineral can be cleaved either by striking it a properly directed blow with a hammer or by pressing upon it in a definite direction with a sharp knife. The planes along which the separation takes place are called cleavage planes. These planes are parallel to possible crystal faces and are so named. Thus, cubical cleavage is parallel to the faces of the cube. The cleavage of a mineral is more developed in a certain direction or in certain directions than in another. If it cleaves exceedingly easily, as does mica, it is said to have perfect cleavage. As mica cleaves in only one direction, it is also said to have cleavage in one direction. Other minerals might be described as having good cleavage in two directions, good basal cleavage, etc. If two cleavages are well developed, the angle between them is often useful for identification. (See augite and hornblende). The cleavage of minerals can often be recognized by the presence and direction of cleavage cracks.

FRACTURE - The fracture of a mineral refers to the character of the surface obtained when crystalline substances are broken in directions other than those along which cleavage may take place. Minerals with poor or no cleavage may yield fracture surfaces very easily.

Types of fracture:

Conchoidal - The surfaces curved and shell-like in appearance (Quartz).

Hackly - Fracture surfaces have many sharp points and are rough and irregular (Copper).

Splintery - Breaks into splinters or fibers.

Even - Fracture surfaces flat or nearly so.

Uneven - Surfaces more uneven (Rhodonite).

PARTING - Parting is breaking on a pre-determined plane, somewhat analogous to cleavage, but much less pronounced. It occurs only on certain planes, whereas cleavage occurs throughout the crystal.

TENACITY - Under this heading is included the behavior of minerals when an attempt is made to break, cut, hammer, crush, bend, or tear them.

The following tenacities are common:

Brittle - Easily broken or powdered and cannot be cut into slices (Quartz).

Ductile - Can be easily drawn into wire (Copper and Silver).

Malleable - Can be hammered out into thin sheets (Gold and Copper).

Secile - Can be cut and yields shavings which crumble when struck with a hammer (Gypsum).

Flexible - Bends, but does not resume its original shape when stress is released.

Elastic - Bends and resumes original shape when stress is released.

MAGNETISM - Minerals, in their natural state, capable of being attracted by a magnet, are said to be magnetic. Magnetite, the magnetic oxide of iron, is the most outstanding of these minerals. Other iron bearing minerals may be weakly magnetic or may be strongly so after heating. For testing weak magnetism in minerals it is best to grind the specimen to the size of ordinary sand grains.

A mineral that acts as a magnet is lodestone, a special form of magnetite.

FEEL OR TOUCH - The impression that can be obtained from handling or touching can be useful in the determination of a few minerals. As examples - talc has a greasy or soapy feel, chalk has a harsh feel, and porous minerals like chalk and kaolin adhere to the tongue.

ODOR - Some minerals give off a characteristic odor when breathed upon, scratched, rubbed, hit with a hammer, or heated.

The more distinctive odors are designated as follows:

Garlic - Produced by friction on arsenopyrite or by heating arsenic compounds.

Sulfurous - Produced by friction on pyrite or by heating of sulfide minerals.

Argillaceous - The claylike odor obtained by breathing upon kaolin.

Fetid - The odor of rotten eggs due to the liberation of hydrogen sulfide.

Horse radish - The odor of decaying horse radish obtained when selenium compounds are heated.

Bituminous - The tarry odor given off by minerals containing bituminous or organic matter.

TASTE - The property of taste can only be applied to those minerals that are soluble in water. Taste is best determined by wetting a fresh fracture of the mineral with the tongue. Some of the following tastes can be noted in certain minerals:

Saline - The salty taste of halite or sodium chloride.

Acid or sour - The taste of sulfuric acid.

Alkaline - The taste of sodium carbonate.

Bitter - The taste of epsom salts.

Cooling - The taste of potassium or sodium nitrate.

Astringent - The taste of alum, which causes a contraction or puckering.

Although taste is not a test that can be used on all minerals, it can aid in a rapid determination of a certain few.

EFFERVESCENCE - When hydrochloric acid is placed on a mineral or in a test tube containing a small portion of pulverized mineral, quick dissolving accompanied by bubbling and hissing is known as effervescence. Sometimes the acid must be warmed to notice this action. Effervescence is a characteristic of carbonate minerals (which give off carbon dioxide) and should be noted when present.

SOLUBILITY - The capability of a finely ground sample of a mineral to enter into a solution or to be dissolved is known as its solubility. In testing the degree of solubility, hydrochloric acid is most commonly used, although nitric or some other acid is required for many metallic minerals.

Many minerals are completely soluble without effervescence, and the color of the solution obtained is in some cases indicative of the elements contained. As examples a yellow solution is obtained if much iron is present, a greenish blue solution after the addition of ammonium hydroxide indicates copper, and pink or pale rose is indicative of cobalt.

FUSIBILITY - The ease with which a mineral melts is its fusibility. Fusibility in minerals grades from those minerals which fuse as large fragments in the alcohol lamp (e.g. stibnite) to those minerals that are entirely infusible (e.g. corundum).

The Scale of Fusibility is as follows:

No.	Mineral	Melting Point	Remarks
1.	Stibnite	525°C	Very easily fusible in candle flame
2.	Chalcopyrite	800°C	Small fragment fuses easily in Bunsen Burner flame
3.	Garnet (Almandite)	1050°C	Fuses easily in blowpipe flame
4.	Actinolite	1200°C	Sharp pointed splinter fuses with little difficulty in blowpipe flame
5.	Orthoclase	1300°C	Thin edges rounded with difficulty in blowpipe flame
6.	Bronzite	1400°C	Only ends of fine splinters rounded in blowpipe flame
7.	Quartz	1710°C	Infusible in blowpipe flame

For ordinary purposes, three grades of fusibility are sufficient:

Easily fusible minerals melt into a globule in the blowpipe flame (1 to 3 of the fusibility scale)

Fusible with difficulty minerals have their edges rounded (4 to 6 in the scale)

Infusible minerals are unaffected by the blowpipe flame.

To test the fusibility of a mineral, select a thin splinter or a very sharp edge of the mineral to be tested. Holding this piece in the forceps, direct the hot oxidizing flame on this thin edge. If the sharp edge rounds off to a glassy or enameled appearance easily, the mineral is said to

be easily fusible. If the sharp edges are rounded with difficulty, the mineral is fusible with difficulty. If the flame has no effect on the edge of the mineral, the mineral is infusible.

ASSOCIATION AND OCCURRENCE - Although neither a physical nor a chemical property, the association of the minerals with each other, and their mode of occurrence often is helpful in identifying a mineral. Thus galena and sphalerite, and azurite and malachite, often are found in pairs.

IDENTIFICATION OF MINERALS BY CHEMICAL METHODS

If the physical characteristics of the mineral are not diagnostic enough for identification, chemical tests can be made with the blowpipe. Many blowpipe tests are simple to make and very little equipment is needed.

The following apparatus is essential:

Blowpipe, alcohol lamp or candle, forceps, charcoal blocks, platinum wire, hammer and anvil, test tubes and holders, open and closed tubes. Where weight is no objection, these may be added; blue glass, watch glasses, test tube support, mortar and pestle, funnel, filter paper, plaster table and litmus paper.

The following reagents are necessary:

Sodium carbonate or soda (Na_2CO_3)

Borax ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$)

Microcosmic salt (or salt of phosphorus)

Tin metal, Zinc metal, Hydrochloric acid (HCl)

Nitric acid (HNO_3), Sulfuric acid (H_2SO_4)

Ammonium hydroxide (NH_4OH), Cobalt nitrate ($\text{Co}(\text{NO}_3)_2$),

Dimethylglyoxime

The following may be added, although they are not necessary: Silver nitrate, AgNO_3 , and Von Kobell's flux, consisting of one part potassium iodide (KI), one part potassium acid sulfate (KHSO_4), and two parts sulfur (S).

In the descriptions of chemical methods, assay means a small amount of the mineral used in a blowpipe test and ignition means heating on charcoal. Volatile means that the substance or its coating is easily converted to a vapor; coatings of volatile substances disappear when touched with a flame.

To use the blowpipe properly, it is necessary to understand the nature of the blowpipe flame. The luminous flame, which may be produced by several sources, is as shown in Fig. 2-2.

In Fig. 2-3 the blowpipe is shown blowing the flame out in a horizontal direction. The reducing flame is located in the region of unburned gases inside the flame, while oxidizing conditions occur outside, where an excess of oxygen exists. A better oxidizing flame is produced by inserting the tip in the flame as shown in Fig. 2-3, while the best reducing flame is produced by holding the tip outside the flame. When a substance is held in the reducing flame, oxygen is removed; when held in the oxidizing flame, the substance may readily combine with the oxygen in the air. The intense heat, of course, hastens the reactions. Blow-piping, like any technique, requires some practice. The best results are obtained by puffing out the cheeks to form an air reservoir, and breathing through the nose, while a gentle steady stream of air exhausts through the blowpipe.

The hottest part of the flame is just beyond the visible blue tip, and this point is used in making fusion tests. When testing a material for fusibility, a fragment having thin edges is held at the hot point (see Fig. 2-3). See Fusibility under Physical and Chemical Properties of Minerals.

Chemical Tests

The following chemical tests all utilize heat, with or without the aid of a blowpipe. They are usually called simply blowpipe tests. Before any of the tests are made, it is necessary that all equipment be clean. If particles of the mineral used in a previous determination are left in the mortar used for grinding, or on the charcoal block, the new determination is worthless.

REACTIONS ON A CHARCOAL SUPPORT - The charcoal support is used to hold the assay while heating with the blowpipe. A portion of the finely ground mineral is placed in a small depression in one end of the charcoal block, which is tilted with the depression at the lower end. See Fig. 2-4. The assay is heated slowly with the oxidizing flame. If the assay decrepitates (breaks up violently) when heated, it should be finely pulverized and moistened with a drop of water.

Usually the assay is heated with sodium carbonate. The mineral is finely pulverized and mixed with three parts of sodium carbonate before heating on the charcoal block.

Much of the time the reason for heating the assay on the charcoal support is to observe the sublimate, if any. The sublimate is a coating on the charcoal, composed of compounds

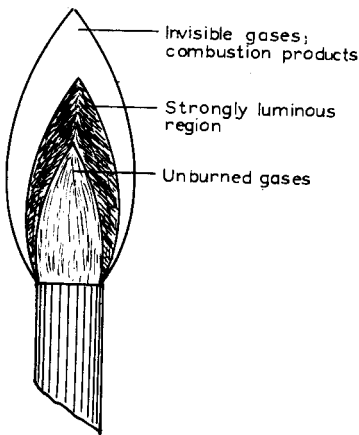


Fig. 2-2. - Luminous Flame

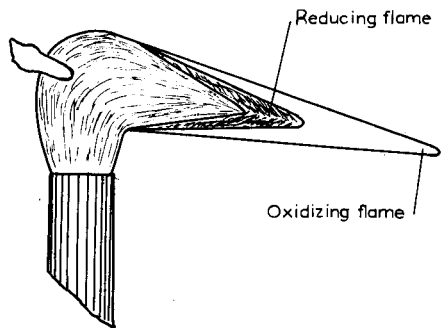


Fig. 2-3. - Blowpipe Flame

of some element in the mineral being tested. These compounds are usually oxides.

FLAME COLORATIONS - Some elements are volatilized by intense heat, imparting characteristic colors to a flame. The best results are obtained by introducing the powdered mineral into the flame on a piece of platinum wire. A quicker, though less decisive method is to strike the mineral a glancing blow with the sharp corner of a hammer, holding the mineral in such a way that tiny fragments are knocked into the flame. Another method is to hold a fragment of the mineral in the flame with forceps. The alcohol lamp or the oxidizing flame of the blowpipe may be used. With certain elements it is a specific compound, i.e. the chloride or the oxide, which gives the color. It is therefore necessary sometimes to wet the powdered mineral with hydrochloric acid or to oxidize it with the oxidizing flame to obtain the color. Some common flame tests are shown in the table of flame colorations.

BEAD TESTS - Bead tests are made by dissolving a small amount of powdered mineral in a flux in a loop on the end of a platinum or "nichrome" wire. The fluxes commonly used are borax and microcosmic salt (which fuses to

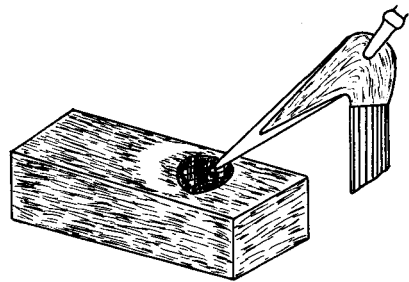


Fig. 2-4. - Heating Assay on Charcoal Support (in oxidizing flame)

Reactions on Charcoal Without Reagents: Sublimates

Arsenic	White. Garlic odor. White to gray at a distance from the assay.
Antimony	White near assay, blue farther away.
Cadmium	Reddish brown to black near the assay. Yellow farther away.
Lead	Near assay, yellow when hot and pale yellow when cold. Bluish white at distance.
Bismuth	Orange yellow when hot and lemon yellow when cold. Greenish white farther from assay.
Molybdenum	Light yellow when hot; white when cold. Reducing flame turns the sublimate dark blue.
Selenium	Steel gray with metallic luster near assay. At distance from assay, white, may have some red.
Tellurium	White near assay. Gray or brown at distance
Thallium	White.
Tin	Faint yellow to white; white when cold. When cobalt nitrate added and heated, becomes green to bluish green.
Zinc	Canary yellow when hot; white when cold. When heated after adding cobalt nitrate, becomes green.

Reactions on Charcoal with Sodium Carbonate

Antimony	Dense white sublimate near the assay. Gray brittle button.
Arsenic	White volatile sublimate, garlic odor.
Bismuth	Lemon-Yellow sublimate. Reddish white, brittle button is formed.
Cadmium	Red-brown to orange sublimate.
Cobalt	Magnetic particles.
Copper	Malleable button.
Gold	Malleable button.
Iron	Magnetic particles
Lead	Yellow coating. Gray Malleable button.
Molybdenum	White sublimate, blue in reducing flame.
Nickel	Magnetic particles
Selenium	Gray sublimate and reddish fumes.
Silver	Malleable button.
Tellurium	White sublimate with red or yellow border.
Tin	Yellow to white coating. White malleable button formed with difficulty.
Zinc	White sublimate, yellow when hot, green spot when moistened with cobalt nitrate and heated.

Flame Colorations

Element	Flame Color	Remarks
Antimony	Pale green	Color plays about assay on charcoal
Arsenic	Pale blue	Garlic odor
Barium	Yellowish green	Alkaline residue after ignition
Boron	Yellowish green	Should be moistened in concentrated sulfuric acid. Rarely gives alkaline residue.
Calcium	Orange to yellow	Should be moistened with hydrochloric acid
Copper	Azure blue	From copper chloride or after moistening with hydrochloric acid
Copper	Emerald green	From copper oxide
Lead	Pale azure blue	Green tinge in outer part, usually accompanied by puff of white smoke
Lithium	Crimson	Does not give alkaline residue after being heated (differs from strontium)
Manganese	Yellowish green	Only the chloride
Molybdenum	Yellow green	From fulfide or oxide
Phosphorus	Pale bluish green	Must be moistened with sulfuric acid; not decisive test
Potassium	Pale violet	May be necessary to heat with gypsum to obtain color
Selenium	Indigo blue	Horse radish odor
*Sodium	Abundant bright yellow	Flame should be very bright and persistent to indicate sodium mineral
Strontium	Crimson	Gives alkaline reaction after heating (differs from lithium)
Tellurium	Pale green	
Zinc	Bluish green	Bright streaks in flame

* Often small amounts of sodium contaminate the sample enough to mask the color of the assay. A blue color screen will filter out the sodium color.
 An alkaline residue is one which, when moistened, will turn red litmus paper blue.

sodium metaphosphate). A loop about 1/16 inch in diameter is made in the end of the wire, and it is cleaned by repeated dipping in hydrochloric acid followed by heating in the flame. It is then heated red hot and dipped in the flux, which adheres to the loop. Heat is applied slowly until the flux forms a clear glassy bead in the loop.

The mineral to be tested is first converted to the oxide by heating in the oxidizing flame until all volatile constituents are driven off. Arsenic especially should be removed because it causes the platinum wire to become brittle. A tiny amount of the oxide is then picked up in the molten bead and the whole bead is reheated in the oxidizing flame. If too much of certain elements are added to the bead, e.g. manganese, the bead may become opaque and the color indistinguishable. Crushing such a bead will allow its color to be determined, but it is best to start over with a smaller amount.

Bead Tests

Oxide of		Borax Bead		Microcosmic Salt	
		Oxidizing Flame	Reducing Flame	Oxidizing Flame	Reducing Flame
Antimony	Hot Cold	Pale Yellow Colorless to white	Pale Yellow Colorless	Pale Yellow Colorless	Gray Gray
Bismuth	Hot Cold	Pale yellow Colorless or white	Gray Gray	Pale yellow Colorless	Gray Gray
Cadmium	Hot Cold	Pale yellow Colorless or white	Pale yellow Colorless	Pale yellow Colorless	Pale yellow Colorless
Chromium	Hot Cold	Yellow to orange Yellowish green	Green Green	Dirty green Green	Dirty green Green
Cobalt	Hot Cold	Blue Blue	Blue Blue	Blue Blue	Blue Blue
Columbium (Niobium)	Hot Cold	Colorless Colorless or white	Colorless Colorless or white	Pale Yellow Colorless	Brown Brown
Copper	Hot Cold	Green Blue	Colorless to green Opaque Red	Green Pale blue	Pale yellowish green Pale blue to ruby red
Iron	Hot Cold	Yellow Yellow to orange	Green Pale green	Yellow Yellow to colorless	Yellow to orange red Almost colorless to violet
Lead	Hot Cold	Pale yellow Colorless or white	Pale yellow Colorless	Pale yellow Colorless	Gray Gray
Manganese	Hot Cold	Violet Reddish violet	Colorless Colorless	Grayish violet Violet	Colorless Colorless
Molybdenum	Hot Cold	Pale yellow Colorless or white	Brown Brown	Yellow green Colorless	Dirty green Green
Nickel	Hot Cold	Violet Reddish brown	Opaque gray Opaque gray	Red to brown red Yellow to red, yellow	Red to brown red Yellow to red, yellow
Silica	Hot Cold	Colorless Colorless	Colorless Colorless	Insol. skeleton Insol. skeleton	Insol. skeleton Insol. skeleton
Titanium	Hot Cold	Pale yellow Colorless to white	Grayish Brownish violet	Pale yellow Colorless	Yellow Violet

Bead Tests continued

Oxide of		Borax Bead		Microcosmic Salt	
		Oxidizing Flame	Reducing Flame	Oxidizing Flame	Reducing Flame
Tungsten	Hot Cold	Pale yellow Colorless	Yellow Yellow to brown	Pale yellow Colorless	Dirty blue Blue
Uranium	Hot Cold	Yellow to orange Yellow	Pale green Pale green to colorless	Yellow Yellowish green	Pale green Green
Vanadium	Hot Cold	Yellow Pale yellow green	Dirty green Green	Yellow Yellow	Dirty green Green

HEATING IN OPEN TUBE - Open tube tests are made in hard glass tubing, about 1/4 inch, inside diameter, and six inches long. The tube is held on an incline, and some of the powdered mineral placed near the bottom. If the tube is first bent, the mineral will not tend to fall out. The heat is first applied above the mineral to create a current of air, then the mineral is heated gradually. A current of air passes over the assay and carries the volatile materials up the tube. See Fig. 2-5. Some of these materials escape as gases, which often give off characteristic odors, and some of them are deposited as sublimates on the cooler parts of the tube.

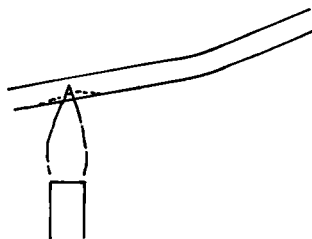


Fig. 2-5. - Open Tube

Open Tube Reactions

Arsenic	White, volatile crystalline (octahedrons) coating at considerable distance from assay
Antimony	White fumes; some condense as powder; if sulphur contained, a pale yellow coating may be formed when hot. Non-volatile
Bismuth	Brown coating while hot; yellow when cold
Bismuth (sulfide)	White powder
Lead (sulfide)	White powder on lower side near the assay, non-volatile
Mercury	Gray metallic globules
Molybdenum	Yellow when hot, white when cold, network of delicate crystals near assay
Selenium	Gray coating of radiating needles, sometimes red selenium
Tellurium	Very white coating, globules; hot, pale yellow

HEATING IN CLOSED TUBE - These tests are made in a glass tube closed at one end or in a small test tube. Small fragments of the mineral are placed in the bottom of the tube and heat is applied gradually. Since little air is available, little oxidation results. Fragments rather than powder should be used. There are two reactions: changes in color of the fragments by the heat, and the formation of sublimates on the inside surface of the tube.

Color Changes in Closed Tube

<u>Element</u>	<u>Before heating</u>	<u>After heating</u>	<u>When cold</u>
Bismuth	White or colorless	Dark yellow to brown	Light yellow to white
Cobalt	Pink	Black	Black
Copper	Blue or green	Black	Black
Hematite	Dark red	Black	Dark red
Iron	Green or brown	Black	Black
Lead	White or colorless	Dark yellow to brown	Light yellow to white
Manganese	Pink	Black	Black
Zinc	White or colorless	Light yellow	White

Closed Tube Reactions

<u>Element or Compound</u>	<u>Sublimate</u>
Ammonium	White
Antimony oxide	White
Antimony sulfide	Black when hot; red-brown when cold
Arsenic	Black in cool part of tube; often gray in warmer part
Arsenic oxide	White
Arsenic sulfide	Dark red liquid when hot; orange solid when cold
Lead chloride	White. Sometimes forms yellow drops
Mercury; amalgam	Gray globules
Mercuric chloride	White, yellow when hot
Mercury sulfide	Very black
Selenium	Black globules. Red when rubbed
Sulfur, some sulfides	Brown-red liquid when hot, yellow when cold
Tellurium	Black globules
Tellurium oxide	Pale yellow when hot, colorless to white when cold
Water	Condenses on the cooler part of the tube

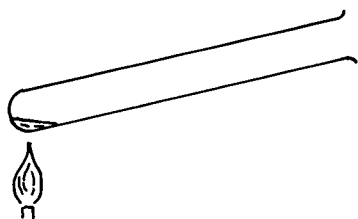


Fig. 2-6. - Closed Tube

REACTIONS ON PLASTER TABLET - A few elements give reactions which can be seen best, or are more decisive, on a plaster of Paris tablet. The tablets are made by spreading wet plaster upon an oiled pane of glass, then cutting into rectangles $1\frac{1}{2}$ by 4 inches while still moist. The plaster tablet is used exactly as in the charcoal support.

There are many characteristic reactions on the plaster tablet, either when the mineral is heated by itself or with reagents. Usually,

however, some other test is just as decisive, so only a few are given here. Reactions of powdered minerals mixed with iodide (Von Kobell's) flux are especially marked.

Some Reactions on Plaster Tablet

Element	Color of Coating	Remarks
Antimony	Orange to red	With iodide flux. Disappears in ammonia fumes
Arsenic	Yellow to orange	With iodide flux. Very volatile. Disappears in ammonia fumes
Bismuth	Brown with underlying red	With iodide flux. Becomes orange yellow and red with ammonia fumes
Cadmium	Greenish yellow with brown	Without flux. Non volatile
Lead	Chrome yellow	With iodide flux
Mercury	Scarlet with yellow and greenish black	With iodide flux; without flux, drab gray
Molybdenum	Ultramarine blue	With iodide flux
Selenium	Red to crimson, black near assay	Without flux. Volatilizes giving horse - rodish odor and reddish fumes
Tellurium	Dark brown	Without flux; volatile; drop of sulfuric acid plus heat gives pink color

OTHER REACTIONS - There are, in addition to the above, the following reactions:

Carbonization - Carbonization (black carbon produced) sometimes occurs when minerals are heated in a closed tube. This indicates the presence of organic substances.

Decrepitation - Many minerals break down to a fine powder when heated. It usually happens rapidly with little crackling explosions. It is usually due to the presence of water in the mineral.

Magnetization - Most iron minerals become magnetic after being heated and then allowed to cool. Cobalt and nickel minerals sometimes react in the same way.

Gases - Heating in a closed tube often causes gases to form in the tube.

BLOWPIPE AND QUALITATIVE TESTS FOR INDIVIDUAL ELEMENTS

Aluminum (Al)

COBALT NITRATE - Light colored and infusible aluminum minerals, when moistened with a drop of cobalt nitrate and intensely heated, assume a blue color. This may be done by holding a thin sliver of the mineral in a forceps or with the powdered mineral in depression on the charcoal block.

PRECIPITATION OF ALUMINUM HYDROXIDE ($\text{Al}(\text{OH})_3$) BY AMMONIUM HYDROXIDE (NH_4OH) - Heat the aluminum-bearing mineral in a strong acid solution. Let the solution cool and then add to it an excess of ammonium hydroxide. A colorless or white flocculent precipitate of aluminum hydroxide indicates the presence of aluminum.

Antimony (Sb)

SUBLIMATE ON CHARCOAL - Place a small portion of the finely ground mineral in a depression on the charcoal. Hold the charcoal in such a position to catch the fumes that come off; and direct the hot oxidizing flame on the mineral. If antimony is present a dense white layer or sublimate will form near the assay. The coating is volatile and bluish.

OPEN TUBE - When heated in an open tube, most antimony minerals yield white fumes, which partly escape and partly condense as a white powder or sublimate along the under side of the tube.

CLOSED TUBE - When heated in a closed tube, antimony oxides form a white sublimate in the shape of needle-like crystals. Sulfides of antimony form black sublimates when hot; reddish brown when cold.

Arsenic (As)

SUBLIMATE ON CHARCOAL - Place a small portion of the finely ground mineral in a depression on the charcoal. Hold the charcoal in such a position to catch the fumes that come off; direct the hot oxidizing flame on the mineral. If arsenic is present a dense white layer or sublimate will form at some distance from the assay. The fumes will have a characteristic garlic odor which antimony does not have.

SUBLIMATE OF ARSENIOUS IODIDE (AsI_3) ON PLASTER TABLET - Place a small portion of the finely ground mineral mixed with iodide flux in a depression on the plaster tablet. Hold the table in such a position as to catch the fumes that come off the mixture as the oxidizing flame is applied to it, using the blowpiping. If arsenic is present an orange-yellow sublimate of arsenious iodide should form around the assay, plus the emission of the characteristic garlic odor.

OPEN TUBE - Arsenic, arsenides, and other arsenic compounds produce a white volatile crystalline sublimate when heated in an open tube. Too rapid heating may give a metallic mirror of arsenic or a yellow coating.

CLOSED TUBE - Arsenic and arsenides give a bright metallic mirror when heated in a closed tube.

Barium (Ba)

PRECIPITATE AS A BARIUM SULFATE - Mix a small amount of powdered minerals with sodium carbonate. Fuse mixture with hot oxidizing flame. Transfer the fusion to a test tube with a small amount of dilute hydrochloric acid and heat until dissolved. When the solution has cooled add small amount of sulfuric acid and white precipitate will form if barium is present. This precipitate is insoluble when water is added and the solution boiled, which distinguishes it from calcium.

FLAME COLOR - When moistened with hydrochloric acid, many barium minerals color the flame yellowish green.

Bismuth (Bi)

SUBLIMATE ON CHARCOAL - Mix the ground mineral with sodium carbonate. Fuse mixture in reducing flame. A yellow sublimate with a white border indicates bismuth present. Reddish metallic globules of bismuth also form.

PRECIPITATE AS BISMUTH OXYCHLORIDE - Mix ground mineral with sodium carbonate and fuse in the oxidizing flame on charcoal. Transfer to a test tube and dissolve in hydrochloric acid. Heat until evaporated almost to dryness. When cool add water. The formation of a white precipitate indicates bismuth.

Boron (B)

FLAME TESTS - Sulfuric acid (H_2SO_4) test. Moisten the mineral in sulfuric acid and then heat in the blowpipe flame. The yellow-green flame resulting may indicate the presence of boron.

Potassium bisulfate ($KHSO_4$) - fluorite test. Mix the powdered mineral with a portion of the potassium bisulfate-fluorite flux. (Three parts potassium bisulfate, one part fluorite). Introduce this mixture into the Bunsen burner flame with a platinum or nichrome wire. Again, the yellow-green flame coloration resulting may indicate the presence of boron.

Bromine (Br) - See Chlorine (Cl)

Cadmium (Cd)

SUBLIMATE ON CHARCOAL - Cadmium minerals heated on charcoal give a sublimate reddish brown near the assay and yellowish green at a distance. May be iridescent.

Calcium (Ca)

FLAME TEST - Powdered calcium minerals moistened with hydrochloric acid color the non-luminous flame yellow, orange or red.

PRECIPITATE AS CALCIUM SULFATE - Dissolve small amount of ground mineral in dilute hydrochloric acid. Add few drops dilute sulfuric acid. A white precipitate of calcium sulfate forms, which will dissolve with the addition of water and application of heat. Distinguishes it from barium sulfate precipitate.

Chlorine (Cl)

PRECIPITATION OF SILVER CHLORIDE (AgCl) BY SILVER NITRATE (AgNO_3) - Fuse with sodium carbonate on charcoal. Gently heat the fusion in dilute nitric acid (HNO_3), add small amount of silver nitrate solution. If chlorine is present a white, gelatinous precipitate of silver chloride results. This is a very sensitive wet test for even traces of chlorine present. May also be used for testing for presence of bromine and iodine, which give results similar to those of chlorine.

Chromium (Cr)

BEAD TESTS - Chromium, if present, colors the borax or microcosmic salt bead green in both the oxidizing and reducing flames.

Chromium minerals color sodium carbonate bead a light yellow in the oxidizing flame and a yellowish green in the reducing flame.

Cobalt (Co)

BEAD TEST - Cobalt, if present, colors borax or microcosmic salt bead blue in both the oxidizing and reducing flames. If copper or nickel also present in the mineral, the bead should be fused with metallic tin on charcoal to bring out the blue color of cobalt.

Columbian (Cb) Also Known As Niobium, (Nb)

REDUCTION TEST WITH TIN - Fuse small portion of the finely ground mineral mixed with sodium carbonate (Na_2CO_3) on charcoal block. Dissolve fused material in a small amount of dilute hydrochloric acid. To this solution add metallic tin. If columbium present the solution upon boiling turns dark blue, compound does not readily change to brown, distinguishing it from tungsten. The blue color of the solution disappears on addition of water.

Copper (Cu)

BLUE COLORATION OF COPPER SOLUTION - Place small portion of finely ground mineral in a test tube. Add dilute nitric acid and heat until dissolved. (If the mineral will not go into solution, fuse with sodium carbonate and then add the nitric acid). After cooling, add more ammonium hydroxide than there is acid. Solution will turn a deep blue if copper is present.

REDUCTION TO METALLIC COPPER - Fuse a little of the finely ground mineral with sodium carbonate and ground charcoal on a charcoal block and globules of metallic copper will form from copper minerals. Sulfide copper minerals should first be roasted before reducing them to metallic copper.

FLAME TEST - Moisten mineral with hydrochloric acid and direct the oxidizing flame on that portion; presence of copper indicated by blue or green coloration of the flame.

BEAD TESTS - If copper is present, borax and microcosmic salt beads fused in oxidizing flame are green when hot and blue-green when cold. Reducing flame forms red bead upon cooling.

Fluorine (F)

ETCHING OF GLASS - Coat one side of piece of window glass with thin layer of paraffin wax and mark through the paraffin with a sharp object. Mix the powdered mineral with few drops of concentrated sulfuric acid and spread over the paraffin coated surface. Let stand for five minutes. If the mineral is a soluble fluoride, glass will be etched where marks penetrate wax.

Iodine (I) See Chlorine (Cl)

Iodine is distinguished from chlorine and bromine in being nearly insoluble in ammonia.

Iron (Fe)

MAGNETISM - Magnetite and pyrrhotite are magnetic before heating but most iron minerals become magnetic when heated in reducing flame and cooled. A small fragment should be used.

PRECIPITATION AS FERRIC HYDROXIDE - Place a small amount of the finely ground mineral in a test tube with a little hydrochloric acid and boil. Add a little nitric acid and boil again. (If the mineral does not dissolve, fuse it with sodium carbonate before the acid treatment.) Cool and then carefully add ammonium hydroxide. A reddish-brown jelly-like precipitate indicates iron.

BEAD TESTS - A borax bead fused in the oxidizing flame will be yellow when cold; fused in

reducing flame it is pale green when cold.

Lead (Pb)

SUBLIMATE ON CHARCOAL AND REDUCTION OF LEAD - Mix finely ground mineral, sodium carbonate, and powdered charcoal, and fuse in the reducing flame on the charcoal block. If lead is present a gray button of metallic lead will form; also a sublimate, yellow near the assay and bluish-white farther away.

PRECIPITATION AS LEAD SULFATE - Place a small amount of the powdered mineral in a test tube with dilute nitric acid and heat until the mineral is dissolved. (If the mineral will not go into solution it will have to be fused with sodium carbonate before the acid treatment.) Cool and add small amount of sulfuric acid. A white precipitate of lead sulfate indicates lead. Hydrochloric acid may be used instead of sulfuric, in which case a white lead chloride precipitate will appear. The chloride or sulfide precipitate can be further tested as in part 1 above.

FLAME TEST - Lead minerals color the flame pale azure blue.

Manganese (Mn)

BEAD TESTS - A borax bead with manganese minerals will be red-violet in the oxidizing flame and colorless in the reducing flame. Fuse a small amount of the mineral with sodium carbonate bead on platinum wire. The presence of manganese is noted by the bluish-green color due to the formation of sodium manganate.

FLAME COLOR - The mineral moistened with hydrochloric acid colors the flame yellowish green.

Mercury (Hg)

CLOSED TUBE - Mix the powdered mineral with sodium carbonate and heat in closed tube. Metallic particles of mercury condense on the tube, and if contents of tube are poured on a piece of paper globules of mercury will be noted.

PRECIPITATION BY COPPER - Boil a small amount of powdered mineral with hydrochloric acid, and then dip a piece of copper wire or foil in this solution. The copper will be coated with a thin layer of mercury if present in the mineral. (Sometimes a quick test is to moisten a copper cent with hydrochloric acid and rub the powdered mineral on it. Shiny white streaks of mercury may coat the copper).

Molybdenum (Mo)

SUBLIMATE ON CHARCOAL - Some minerals, heated by the oxidizing flame, give a yellow sublimate on the charcoal when hot, which turns white upon cooling. This white coating, when touched with the reducing flame, changes to a deep blue. A copper-red sublimate also surrounds assay; best seen in reflected light.

BEAD TESTS - Microcosmic salt bead is colorless in oxidizing flame; green in reducing flame. Borax bead is colorless in oxidizing flame; brown in reducing flame.

COLOR IN SOLUTION - Place a small amount of the powdered mineral in a test tube with a few drops of concentrated sulfuric acid and a few drops of water, and add a small scrap of paper. Heat until acid fumes appear, let cool, then add water one drop at a time. A deep blue color is produced which quickly disappears each time.

Nickel (Ni)

PRECIPITATION WITH DIMETHYLGLYOXIME - Dissolve a small amount of powdered mineral in nitric acid. (If the mineral is not soluble in acid, it will have to be fused with sodium carbonate before the acid treatment). Allow solution to cool, then add more ammonium hydroxide than there is acid. To this alkaline solution add a few drops of dimethylglyoxime. A scarlet jelly-like substance at the top of the solution indicates nickel. (A quick field test is to moisten mineral with nitric acid, neutralize with ammonium hydroxide, and add dimethylglyoxime. A red color indicates nickel. The failure of this test should not be taken to mean nickel is absent).

BEAD TESTS - The borax bead, in the oxidizing flame, is reddish brown; gray in the reducing flame. The microcosmic salt bead, in the oxidizing flame, is pale to red yellow; yellow to orange in the reducing flame.

Niobium (Nb) See Columbium (Cb)

Phosphorus (P)

PRECIPITATION OF AMMONIUM PHOSPHOMOLYBDATE WITH AMMONIUM MOLYBDATE - Gently heat the mineral in dilute nitric acid. A few drops of this solution added to an excess of ammonium molybdate gives a canary-yellow precipitate of ammonium phosphomolybdate if phosphorus present.

FLAME TEST - Moisten the edge of the mineral with concentrated sulfuric acid and place in the flame. A pale bluish-green flame may indicate the presence of phosphorus.

Selenium (Se)

ODOR AND SUBLIMATE ON CHARCOAL - Brown fumes and a silvery coating with a border of red are indications of selenium. Fumes have a horse radish smell. The sublimate gives azure blue flame in reducing flame.

Silica (Si)

JELLY - Boil finely pulverized mineral in hydrochloric acid in a test tube. If silica is present a jelly will form.

Silver (Ag)

REDUCTION TO METALLIC SILVER - Mix the powdered mineral with sodium carbonate, and fuse on charcoal. A metallic globule of silver will form. Roasting in the oxidizing flame should precede the fusion if sulfur, arsenic, or antimony are present.

PRECIPITATION AS SILVER CHLORIDE - Dissolve a small portion of the powdered mineral in nitric acid; allow to cool, and add a little hydrochloric acid. A white, curdy precipitate forms if silver is present. As a further check add ammonium hydroxide and the precipitate will disappear.

Sodium (Na)

FLAME TEST - The sodium-containing mineral will emit a strong distinct yellow flame when scraped dry into the Bunsen burner flame. A trace of sodium will color the flame, and any appreciable amount will cause the yellow flame to mask all other colors.

Strontium (Sr)

FLAME TEST - Strontium-containing minerals emit a strong and distinct crimson flame when scraped dry into the Bunsen burner flame. The best results are obtained when the mineral is moistened with hydrochloric acid before the flame is applied. The strontium flame is persistent and abundant. Lithium gives a similar flame, but may be distinguished by the following test.

PRECIPITATION OF STRONTIUM SULFATE WITH SULFURIC ACID - Dissolve the strontium mineral in dilute hydrochloric acid, add small amount of sulfuric acid. The formation of white slightly soluble precipitate may indicate the presence of strontium (See Calcium and Barium).

Sulfur (S)

FUSION WITH SODIUM CARBONATE - Mix a little of the powdered mineral with sodium carbonate. Fuse this mixture on charcoal. After the fusion is cool, place it on a silver coin and grind it thoroughly with the blade of a knife or some other flat object. To the ground fusion add a drop or two of water and let stand for two or three minutes. Wash the coin thoroughly and if after washing the coin is stained brown or black, sulfur is present. If you do not get a reaction the first time try again with more thorough fusion.

OPEN TUBE - Sulfides oxidize when heated in an open tube, giving off the pungent odor of sulfur dioxide.

CLOSED TUBE - In a closed tube, sulfur is liberated from some sulfides. It is red when hot, and changes to a yellow solid when cold.

OXIDATION WITH NITRIC ACID - Hot concentrated nitric acid oxidizes sulfides to sulfates, liberating some free sulfur which rises to the surface. The sulfur may be yellow or blackened with particles of the mineral. Red nitrogen dioxide fumes are liberated.

Tellurium (Te)

SUBLIMATE ON CHARCOAL - When heated with the oxidizing flame on charcoal, a white sublimate is formed near the assay. This coating is volatile and makes a light green flame when touched with the reducing flame.

COLOR OF SOLUTION - Gently heat the powdered mineral in concentrated sulfuric acid.

A reddish violet color indicates tellurium. After cooling add water and the color disappears and a grayish black precipitate of tellurium forms.

Tin (Sn)

REACTION WITH METALLIC ZINC - Place a piece of the mineral in a test tube and add enough metallic zinc to surround the mineral fragment. Add enough dilute hydrochloric acid to cover the mineral and zinc and warm gently for several minutes. Pour the contents of the test tube out and recover the mineral. If tin is present the mineral will have a dull gray coating of tin which becomes bright when rubbed between the fingers.

REDUCTION AND SUBLIMATE ON CHARCOAL - Mix the powdered mineral with one part powdered charcoal and two parts sodium carbonate and fuse in the reducing flame on the charcoal block. Globules of bright metallic tin will form, which are bright in the reducing flame and dull after cooling. Long continued ignition will give a white sublimate on charcoal.

Titanium (Ti)

OXIDATION WITH HYDROGEN PEROXIDE - Mix the powdered mineral with sodium carbonate and fuse in the oxidizing flame. Place the cool fusion in a test tube and add a little dilute sulfuric acid. Heat gently for a short time and then allow the solution to cool. With the addition of a small amount of water and a few drops of hydrogen peroxide, the solution will turn a pale yellow to orange-red if titanium is present.

REDUCTION WITH METALLIC TIN - Fuse the powdered mineral with sodium carbonate and dissolve the fusion in hydrochloric acid. To the acid solution add a little metallic tin and boil for a few minutes. If titanium is present the solution will assume a violet color. The boiling may have to be continued nearly to dryness.

BEAD TESTS - Titanium minerals in the borax bead are colorless in the oxidizing flame, brown-violet in the reducing flame. Titanium minerals in the microcosmic salt bead are colorless in the oxidizing flame, violet in the reducing flame.

Tungsten (W)

REDUCTION WITH METALLIC TIN - Fuse the powdered mineral with sodium carbonate and transfer the fusion to a test tube. Dissolve the fusion with hot water. Add a little concentrated hydrochloric acid to the cool solution and a white precipitate will form. Upon boiling, this turns into a yellow precipitate of tungstic acid. Add a little metallic tin and boil again, and a blue solution will appear. Prolonged reduction with tin will produce a brown color.

BEAD TESTS - In the borax bead, the tungsten minerals are colorless in the oxidizing flame, yellow to brown in the reducing flame. In the microcosmic salt bead, the tungsten minerals are colorless in the oxidizing flame, blue in the reducing flame.

Uranium (U)

BEAD TESTS - In the microcosmic salt bead, uranium minerals are yellow green in the oxidizing flame, bright green in the reducing flame. In the borax bead, uranium minerals are yellow in the oxidizing flame, light green to colorless in the reducing flame. Both beads are fluorescent under ultraviolet light.

RADIOACTIVITY - Test for radioactivity with a counter or electroscope. (See Chapter 15).

Vanadium (V)

BEAD TESTS - Vanadium minerals in a borax bead are yellowish green in the oxidizing flame, bright green in the reducing flame. The microcosmic salt bead is light yellow in the oxidizing flame, bright green in the reducing flame.

Water (H₂O)

Grind the mineral finely and heat a portion in a closed tube. If water is present it will form on the sides of the tube and run down. Heat the tube before this test to be sure there is no moisture present in the tube itself. Only fresh, dry specimens must be used.

Zinc (Zn)

SUBLIMATE ON CHARCOAL - Mix the powdered mineral with one part charcoal and two parts sodium carbonate. Heat this mixture on a charcoal block; a pale yellow sublimate is formed close to the assay. The sublimate becomes white on cooling. Add a drop of cobalt nitrate to the mineral and to the sublimate and heat again. A spot of green on the mineral and

sublimate signifies the presence of zinc.

COLOR WITH COBALT NITRATE - If the mineral is light colored and infusible the powdered mineral moistened with cobalt nitrate and intensely ignited will assume a blue or green color.

FLAME COLOR - Some zinc minerals burn as streaks or threads of bluish green in the flame.

DESCRIPTIONS OF MINERALS

Actinolite (See Asbestos And Tremolite)

Anglesite $PbSO_4$ (68.3% Lead)

Colorless, white, pale yellow. H, 3; G, 6.2 to 6.4. Adamantine luster, sometimes resinous or vitreous. Transparent on thin edges. Imperfect cleavage. Brittle. Fuses easily in candle flame; decrepitate in blowpipe flame; forms lead globule in reducing flame. Soluble in hot hydrochloric acid after fusion with soda. (Cerussite effervesces in nitric acid.) Distinguished by high G and non-metallic luster. Common oxidation product of lead minerals, especially galena. Found in cracks and cavities in zone of oxidation with galena and cerussite. Also associated with sphalerite, smithsonite, hemimorphite and limonite. An ore of lead.

Anhydrite $CaSO_4$

Color, white, sometimes grayish, bluish, reddish, or black. Streak, grayish white. H, 3-3.5; G, 2.9. Luster, pearly, greasy or vitreous. Transparent to translucent. Good cleavage, yields rectangular fragments. Brittle. Crystals not common. Conchoidal fracture. Sometimes resembles marble or lumps of sugar. Found with gypsum and other evaporites. Harder than gypsum, does not effervesce with acids.

Apatite $Ca_5(F, Cl, OH)(PO_4)_3$

Color, green, brown, occasionally blue or colorless. Streak white. H, 5; G, 3.2. Vitreous to subresinous luster. Transparent to translucent. Commonly in long prismatic crystals, sometimes short or tabular crystals terminated by pyramids. Also massive granular or compact. Sometimes fibrous or rounded. Conchoidal to uneven fracture. Brittle. Fusible with difficulty. Phosphorus and calcium tests. Fluorine, chlorine and hydroxyl substitute for each other, forming an isomorphous series. When fluorine alone is present, the mineral is fluorapatite; chlorine alone gives chlorapatite; hydroxyl alone gives hydroxylapatite. Distinguished from beryl by hardness (softer than knife) and pyramidal termination of crystals. Widespread as an accessory mineral in igneous, sedimentary, and metamorphic rocks. Found with titaniferous magnetite bodies or as separate deposits. Used as source of fertilizer.

Argentite (Silver Glance) Ag_2S (87.1% Silver)

Color, dark lead gray. Streak, shiny lead-gray. H, 2 to 2.5; G, 7.2 to 7.4. High metallic luster on fresh surface; becomes dull and black on exposure. Crystals not common. Generally disseminated, coatings or arborescent. Very sectile. On charcoal fuses easily with intumescence, yielding sulphur dioxide fumes and globule of silver. Associated with other silver minerals, galena, pyrite and sphalerite. Important silver ore.

Arsenic As (100% Arsenic Minus Impurities)

Color, tin white on fresh fracture surface, tarnishes dark gray to black. Tin white to gray streak. H, 3.5; G, 5.7. Metallic luster. Opaque. Very brittle, easily powdered with a hammer. Rare in U. S., occurs in compact, scaly, granular or fine-grained masses. Often breaks into concentric or onion-like layers. Basal cleavage not very conspicuous. Often contains antimony and traces of bismuth, silver, iron or gold. Found in veins with silver, cobalt and nickel ores. (Native arsenic furnishes but a small portion of the arsenic used in commerce and industry.)

Arsenopyrite (Mispickel) $FeAsS$ (46% Arsenic)

Color, silver white to light steel gray. Streak black. H, 5.5 to 6; G, 5.9 to 6.2. Metallic luster. Opaque. Easily fusible to magnetic globule. Arsenic sublimate; garlic odor. Massive, compact, granular, columnar, or radial. Often contains cobalt (which may replace part of arsenic), antimony, bismuth, gold and silver. (Looks like cobaltite and skutterudite. Distinguished by putting a piece in nitric acid: arsenopyrite will not materially change the color of the fluid. Other two turn it rose-red. All give off smell of sulfur). Common vein mineral often associated with gold; occurs with other sulfides. Used as a source of arsenic,

which is used in poison, glass, preservatives, and some paints

Asbestos Group

Asbestos is the name for a group of fibrous minerals, divided into serpentine asbestos and amphibole asbestos. Most important serpentine asbestos is chrysotile; most important amphibole asbestos are crocidolite, amosite, and tremolite. Actinolite—coarse green variety, quite common, though worthless. Chrysotile is most important commercially, followed by crocidolite and amosite. Color, white, green, yellowish, bluish. Colorless streak. H, 2 to 6; G, 2.2 to 3.3. Luster silky, dull. Translucent to opaque, fibrous, infusible. Characteristic fibrous asbestos structure most distinguishing feature. Occurs with serpentine or amphibole minerals, dependent on type. Associated with ultrabasic rocks or magnesian limestones or dolomites.

Augite (Complex Silicate of Ca, Mg, Fe, Al.)

Augite is the most common pyroxene. (The pyroxenes are a group of dark silicate minerals.) Color, black or greenish black, also leek green. Streak, grayish green. H, 5 to 6; G, 3.2. Vitreous to dull luster. Short crystals common, also compact and disseminated grains and aggregates. Cleavage 87° and 93° . Fusible with difficulty and often forms magnetic glass. Insoluble in acids. Common rock mineral in dark basic rocks. (See Chapter 3 for more distinguishing features.)

Azurite (Blue Copper Carbonate) $2\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$ (55.3% Copper)

Color, azure blue. Streak, light blue. H, 3.5 to 4; G, 3.8. Vitreous luster. Transparent to translucent. Effervesces in hydrochloric acid. Brittle. Commonly in botryoidal masses; radial, fibrous structure. Associated with malachite, cuprite, native copper, chalcocite, chalcocopyrite and bornite. Almost always with malachite, but less abundant. Used as ore of copper.

Barite (Heavy Spar, Barytes) BaSO_4

Colorless, white, light shades of yellow, blue, red. Streak white. H, 3 to 3.5; G, 4.5. Vitreous to pearly luster. Transparent to opaque. Turns flame green. Crystals very common, usually well-developed. Also in masses. Perfect basal and prismatic cleavage. Oxides of strontium and calcium sometimes present. Occurs as gangue (Chapter 7) in veins associated with ores of lead, silver, copper, cobalt, manganese, antimony. Also found in pockets in limestone associated with calcite and celestite. Used in oil well drilling, in manufacture of paint, wall paper, glass, insecticides.

Bauxite $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$, approximately

Bauxite is not a true mineral species, but a mixture of hydrous aluminum oxides. Color, white, gray, brown, yellow, or reddish. Streak, variable. Dull to earthy luster. H, 1 to 3; G, 2 to 2.5. Psilotic or oolitic, earthy masses. Bauxite is product of tropical or subtropical weathering of aluminous rocks. Used as source of aluminum and bauxite brick.

Beryl $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$

Color, various shades of green, blue, yellow and reddish; sometimes mottled. H, 7.5 to 8; G, 2.8. Vitreous luster. Transparent to translucent. Hexagonal prismatic crystals common. Also in columnar and compact masses and rounded grains. Fuses with great difficulty, turning white and cloudy. Yields little water on intense ignition. Beryllium may be partially replaced by varying amounts of calcium, iron, potassium, sodium, and cesium. Alters to mica and kaolin. Commonly found in pegmatite dikes; also in granitic rocks, mica, schist, and limestone. Associated with quartz, feldspar, mica, topaz, tourmaline, cassiterite, garnet, zircon, corundum. Used for gems and as source of beryllium. Color is basis of naming gems. Aquamarine (transparent greenish blue); emerald (deep green); rose beryl; golden beryl.

Biotite (Black Mica) Hydrous Complex Silicate

Color, dark brown or black; rarely light brown or greenish. Streak white to greenish. H, 2.5 to 3; G, 2.9. Transparent to opaque. Perfect micaceous cleavage one direction. Crystals rare. Found in plates, masses or disseminated scales. May contain titanium, sodium, fluorine. Fuses with difficulty. Only slightly attacked by hydrochloric acid. Decomposed by hot concentrated sulfuric acid, giving milky solution. Water in closed tube. Alters to chlorite, epidote or iron oxide. Less resistive to weathering than muscovite. Common in granite, gneiss, mica schist. Often associated with muscovite. Of little use commercially.

Bismuth (100% Bismuth minus impurities) Bi

Color, silver with reddish tone, often with brassy tarnish colors. Streak, same as color. H, 2 to 2.5; G, 9.8. Usually laminated, granular, arborescent, may have perfect cleavage one direction. Easily fusible to metallic globule on charcoal. Bismuth tests. Native bismuth often contains traces of arsenic, sulfur, antimony and tellurium. Comparatively rare, found in veins associated with silver, cobalt, lead, zinc and tin ores. Minor ore of bismuth, which is used in easily fusible alloys.

Bismuthinite Bi_2S_3 (81.2% Bismuth)

Color, lead gray, inclining to tin white, with a yellowish or iridescent tarnish. Streak, gray. H, 2; G, 6.7. Metallic luster. Opaque. Somewhat sectile. Rarely in crystals. Usually massive, foliated or fibrous. Sometimes contains some copper, antimony, lead, iron. Bismuthinite is comparatively rare. Usually primary mineral, but at times found in secondary sulfide zone. Occurs with igneous rocks, associated especially with bismuth, chalcocopyrite, and cassiterite. Sometimes associated with tin and tungsten ores. Ore of bismuth.

Bornite (Peacock Ore, Purple Copper Ore) Cu_5FeS_4 (63.3% Copper)

Color on fresh fracture between bronze and copper red, tarnishes quickly to brilliant peacock colors to almost black. Streak, gray black. H, 3; G, 5.1. Metallic luster. Fusible in blowpipe flame to brittle globule; becomes magnetic in reducing flame. Usually compact to granular massive. Occurs with other copper minerals; also with cassiterite, pyrite, siderite. Alters readily to chalcocite and covellite. Ore of copper.

Calcite CaCO_3

Colorless, white, may be shades of almost any color. H, 3; G, 2.7. Vitreous to earthy luster. Transparent to opaque. Highly perfect rhombohedral cleavage. Common in good crystals which are doubly refracting. Many forms have been observed. Also occurs in masses. May be pure or mixed with other elements or minerals. Easily soluble with brisk effervescence in cold dilute acids. Very widely distributed. Occurs as limestone, marble and chalk over wide areas, also as gangue in metalliferous ore deposits. Used in cement and lime; chalk used for crayons; clear variety Iceland Spar, used in optical instruments; marble used for decoration and building.

Carnotite $\text{K}_2\text{O} \cdot 2\text{UO}_3 \cdot \text{V}_2\text{O}_5 \cdot 3\text{H}_2\text{O}$, Approximately

Color, canary to lemon yellow. H, 1 to 2; G, approximately 5. Dull to earthy luster. Transparent to translucent. Radioactive. Perfect basal cleavage. Crystals small and rare. Usually in incrustations, or as a crystalline powder. Occurs as powdery incrustations in loose masses or as an impregnation in sand or sandstone. Found mainly on Colorado Plateau. An important source of radium.

Cassiterite (Tin Stone) SnO_2 (78.6% Tin)

Color, brown, reddish brown, black, rarely yellow or white. Streak white to pale brown. H, 6 to 7; G, 7. Adamantine to submetallic luster. Found as crystals, disseminated masses or grains, or as pebbles. Infusible, insoluble. Commonly associated with wolframite, arsenopyrite, topaz, fluorite. Occurs in veins or in rocks, intruded by pegmatite. Cassiterite is resistant to weathering, so is often found as angular and rounded grains and pebbles in sands and gravels in streams (stream tin). Botryoidal masses with fibrous radial structure called "wood tin."

Celestite SrSO_4

Color, white, bluish, reddish. H, 3-3.5; G, 3.9-4. Vitreous to pearly luster. Tabular or prismatic crystals; also fibrous, granular or cleavable masses. Good cleavage two directions. Transparent to translucent. Decrepitates, fuses to white pearl, colors flame red. Does not effervesce with acid. Associated with limestone or sandstone, with gypsum, sulfur, halite. Disseminated or in cavities. A source of strontium compounds.

Cerargyrite (Horn Silver) AgCl (75% silver)

Colorless to pearl gray. Darkens to violet brown on exposure to light. H, 2-3; G, 5.5. Sectile, cuts like horn. Very easily fusible to silver globule. Massive with waxlike or hornlike appearance. Tests for silver and chloride. Secondary mineral, therefore found in upper parts of silver veins. Important secondary ore of silver.

Cerrusite PbCO_3 (77.5% Lead)

Colorless, white or gray. Streak, white. H, 3 to 3.5; G, 6.4 to 6.6. Adamantine luster, sometimes pearly. Transparent to almost opaque. Easily fusible to lead globule in charcoal with soda. Soluble in warm dilute nitric acid with effervescence. Crystals frequently in clusters or star-shaped groups. Twins common. Often granular and compact masses, rarely fibrous. May contain some silver and zinc. Occurs as a pseudomorph after galena and anglesite. Common lead mineral found in the upper levels (oxidized zone) of galena deposits with other minerals of the oxidized zone. Associated with galena, anglesite. Important ore of lead and silver.

Cervantite $\text{Sb}_2\text{O}_3 \cdot \text{Sb}_2\text{O}_5$

Color, canary yellow to white. Streak, yellowish white to white. H, 4.5; G, 4. Greasy, pearly or earthy luster. Earthy or massive. Hardness appears less in earthy varieties. Infusible, soluble in hydrochloric acid. Secondary antimony mineral, found as coating on stibnite, and with other secondary antimony and arsenic minerals.

Chalcedony SiO_2 (An Amorphous Variety Of Quartz)

Color, white, grayish, brown, blue or black. H, 7; G, 2.6. Waxy luster. Translucent to opaque. Commonly stalactitic, botryoidal, concretionary, and lining cavities. Special varieties of chalcedony are precious and semi-precious stones. (See Gemstones).

Chalcocite (Copper Glance) Cu_2S (79.8% Copper)

Color, dark lead-gray, often tarnished blue or greenish. Streak, shiny lead-gray. H, 2.5 to 3; G, 5.5 to 5.8. High metallic luster on fresh surface, which soon becomes dull and black. Imperfect sectile. Easily reduced to metallic copper on charcoal. Copper flame color. Associated with other copper minerals. An important ore of copper.

Chalcopyrite (Copper pyrites, Yellow Copper Ore) CuFeS_2 (34.5% Copper)

Color, brass yellow; tarnishes to various blue, purple, and blackish tints; often iridescent. Streak, greenish black. H, 3.5 to 4; G, 4.1 to 4.3. Uneven fracture. Commonly in compact or disseminated masses. Easily fusible to magnetic globule on charcoal. Contains at times small amounts of gold and silver; also selenium, thallium, and arsenic. Chalcopyrite resembles pyrite, but is softer, its color is a more golden yellow, and it tarnishes to iridescent colors. Most common copper mineral. In veins with pyrite, sphalerite, galena and copper minerals. Important ore of copper.

Chlorite (Hydrous Magnesium Iron Aluminum Silicates)

The term chlorite is applied to a group of related mica-like minerals. Color, green, brownish, or blackish green. Streak, greenish. H, 1 to 2.5; G, 2.6 to 3. Perfect cleavage one direction. In granular, foliated, scaly or earthy masses; often as scaly coating. Flexible scales. Soapy feel. Translucent to opaque. Yields water in closed tube. Of secondary origin, derived from ferromagnesian minerals. Often in schist or serpentine.

Chromite (Chrome Iron) FeCr_2O_4

Color, black. Streak, dark brown. Opaque. Sometimes slightly magnetic. H, 5.5; G, 4.6. Submetallic to metallic luster. Indistinct cleavage. Uneven to conchoidal fracture. Usually in fine granular, compact masses, or as disseminated grains. May contain magnesium and aluminum. Infusible; becomes magnetic when heated with soda on charcoal. Occurs as segregations, usually layers or lenses in ultrabasic rocks, notably dunite. Used in steels, and as a refractory.

Chrysocolla $\text{CuSiO}_3 \cdot 2\text{H}_2\text{O}$ (36.1% Copper)

Color, usually green to turquoise blue; when impure, brown to black. Streak white. Translucent to opaque. Vitreous, greasy to earthy luster. H, 2 to 4; G, 2 to 2.2. Conchoidal fracture. Almost always occurs in compact, reniform or earthy masses; also as incrustations and stains. May have an enamel-like appearance and resemble opal. Infusible. Decomposed by hydrochloric acid, but does not gelatinize. Yields water. Chrysocolla is a secondary mineral, formed by the alteration of various copper ores. Generally found in the zone of oxidation of copper ore deposits. Associated with other copper minerals. An ore of copper. Sometimes cut and polished for gems.

Cinnabar HgS

Color varies with impurities and structure and may be scarlet, brownish red, brown, black or lead gray. Streak, scarlet to reddish brown. H , 2.5; G , 8. Adamantine to dull luster. In thin plates transparent, otherwise opaque. Usually in fine grained masses, crystalline crusts, powdery coatings or disseminated blebs. Streak and bright red color usually enough to identify, but some darker varieties resemble cuprite or hematite. Distinguished by specific gravity and hardness. If moistened with hydrochloric acid and rubbed on clean copper, a silver-white streak is produced. Found in veins, disseminated, or in irregular masses in sedimentary rocks. Usual associates are low temperature minerals, native mercury, pyrite, marcasite, realgar, calcite, stibnite, sulfides of copper. Chief source of metallic mercury.

Cobaltite (Cobalt Glance) CoAsS

Color, silver white, inclined to red; grayish if much iron present. Streak, grayish black. H , 5.5; G , 6 to 6.4 (increases with amount of tantalum present). Cubical cleavage. Metallic luster. Uneven fracture. Brittle. Opaque. Commonly as small well-developed crystals showing either the cube or pyritohedron (which has five sided faces). Fuses to metallic globule on charcoal. Usually contains iron (up to 10 per cent). Arsenic odor and sublimate. Generally in high temperature deposits with other cobalt and nickel minerals. A source of cobalt.

Columbite $\text{Fe}(\text{NbO}_3)_2$, Tantalite $(\text{Fe}, \text{Mn})[(\text{Nb}, \text{Ta})\text{O}_3]_2$ (Columbium is also known as Niobium)

Columbite grades into tantalite by substitution of tantalum for columbium. Color, black to brown. Streak, brownish, reddish or black. H , 6; G , 5.2 to 7.9. Often in square prisms. Conchoidal to uneven fracture, often with iridescent tarnish. Short thick crystals; also massive and disseminated. Submetallic to dull luster. Composition varies greatly. Frequently contains small amounts of tin and tungsten. Fusible with difficulty. Not attacked by acids. Fused with soda on charcoal becomes magnetic. Occurs in granite rocks and pegmatites, associated with beryl, tourmaline, spodumene, quartz, feldspar, wolframite, and cassiterite. An important source of columbium and tantalum. Columbium is used in high speed steels, tantalum in high corrosion-resistant metals.

Copper (Native Copper) Cu (100% Copper Minus Impurities)

Color copper red on fresh fracture. Due to tarnish and decomposition products, color may be superficially black, red, green, or blue. Streak copper red, metallic and shiny. H , 2.5 to 3; G , 8.9. Metallic luster. Highly ductile and malleable. Hackly fracture. Fuses to copper globule in blowpipe flame. Almost pure copper; sometimes contains small amounts of silver, arsenic, mercury, antimony. Generally in scales, grains, plates, and masses, sometimes weighing many tons; less frequently dendritic. Some common associates are calcite, quartz, epidote, and zeolites. Most noteworthy occurrences are in cavities, in amygdaloidal lavas and as cement in conglomerates. Ore of copper.

Corundum Al_2O_3

Color, usually some shade of brown, pink or blue; also white, gray, green, yellow, colorless; sometimes multicolored. Transparent to translucent. H , 9; G , 3.9 to 4.1. Adamantine to vitreous luster. Luminescence sometimes observed, especially in gem varieties. Conchoidal fracture. Well-developed crystals common and often rather large. Occurs also in compact granular masses. Crystals usually prismatic or barrel shaped. Crystals are usually quite pure. Small amounts of ferric oxide may be present as a pigment. Varieties of corundum: Ruby, transparent deep-red gem variety; Sapphire, transparent blue gem. Transparent stones of other colors are called yellow, golden, or white sapphires; Emery is an intimate mixture of corundum, magnetite, hematite, quartz and spinel; dark gray to black in color; H , 7 to 9. Usually occurs disseminated as accessory mineral in metamorphic rocks and certain igneous rocks, especially those deficient in silica. Commonly associated with magnetite, mica, chlorite, nephelite, serpentine, and spinel. Used for abrasives and gems.

Covellite CuS (66.4% Copper)

Color, indigo blue or darker. Sometimes has a purple iridescence. Often shows fine purple color when moistened with water. Streak, lead gray to black. H , 1.5 to 2; G , 4.6. Luster metallic to submetallic. Perfect basal cleavage, yielding flexible thin plates. Opaque. Easily fusible in blowpipe flame. Copper flame color. Crystals usually thin hexagonal plates. Often massive. Occurs in copper veins associated with other copper minerals: chalcocite, bornite, enargite, etc., and is secondary in origin. Frequently in intimate intergrowth with

chalcocite. Ore of copper.

Cryolite Na_3AlF_6

Colorless to snow white, more rarely reddish, brownish, or black. H, 2.5; G, 3. Luster, vitreous to greasy. Often resembles paraffin. Transparent to translucent. Powdered mineral almost disappears in water. Basal and prismatic cleavages, three directions nearly at right angles. Uneven fracture. Easily fusible, producing intense yellow sodium flame. Crystals rare, usually cubical in habit. Usually in compact, granular, or cleavable masses. Only important occurrence is on west coast of Greenland in a veinlike mass in granite. Cryolite is associated with siderite, chalcopyrite, and sphalerite. Used as an electrolytic bath in manufacture of aluminum.

Cuprite (Ruby Copper Ore) Cu_2O (88.8% Copper)

Color, ruby red to almost black. Streak, brownish red in various shades. H, 3.5 to 4; G, 6.1. Adamantine, submetallic to earthy luster. Transparent to opaque. Fusible to copper globe in reducing flame on charcoal. Copper flame color. Crystals common, usually cubic or octahedron, also compact, granular, and earthy massive; fine slender aggregates called plush copper. Usually pure. Alters readily to malachite, azurite, and native copper. Pseudomorphs of malachite after cuprite are rather common. Cuprite is a secondary mineral and found in upper parts of deposits with other secondary copper minerals such as malachite, azurite, native copper. Important ore of copper.

Dolomite (Pearl Spar) $\text{CaMg}(\text{CO}_3)_2$

Color reddish, yellow, brown, white, or black, rarely colorless. Streak, white to pink or gray. H, 3.5 to 4; G, 2.9. Perfect rhombohedral cleavage. Vitreous to pearly luster. Transparent to translucent. Crystals are common. The faces are frequently curved, forming saddle-shaped crystals. Also in fine to coarse grained cleavable or compact masses. Infusible; fragments are but slightly acted upon by cold dilute acid but powder effervesces. Dolomite occurs abundantly as dolomitic limestone with calcite. Used for building and ornamental purposes; as a source of magnesium compounds; and as refractory material.

Enargite Cu_3AsS_4 (48.3% Copper)

Color, grayish black to iron black. Streak, black. H, 3; G, 4.4. Perfect prismatic cleavage, columnar structure. Uneven fractures. Submetallic luster. Opaque. Sooty, darker than stibnite. Copper and arsenic tests. May contain some iron, zinc, and antimony. In veins with other copper minerals, also pyrite. Ore of copper, also source of arsenious oxide.

Epidote $\text{Ca}_2(\text{Al}, \text{Fe})_3(\text{OH})(\text{SiO}_4)_3$

Color, pistachia or yellowish to blackish green; rarely gray or black. Crystals are usually darker in color than massive varieties. H, 6 to 7; G, 3.3 to 3.5. Vitreous to resinous luster. Transparent to opaque. Perfect cleavage one direction, uneven fracture. Crystals rather common; usually elongated and deeply striated. Also in divergent or parallel fibrous and columnar aggregates, coarse to fine granular masses, or in rounded or angular grains. Yields a little water in closed tube when strongly ignited. Gelatinizes with hydrochloric acid after ignition. Fusible with difficulty to light colored slag (with intumescence). Epidote is a typical metamorphic mineral, in contact metamorphic zones and often occurs extensively, forming epidote rocks. Commonly associated with chlorite, hornblende in schists, native copper and the zeolites. Sometimes used for gems.

Feldspar Group

The feldspar group is composed of 1) orthoclase and microcline, which are identical chemically and 2) the plagioclase series. Certain igneous rocks are classified according to the kind of feldspar they contain (See Chapter 3). All feldspars have certain properties in common, among them two good cleavages almost at right angles to each other; they have the same hardness (6); and they exhibit well defined crystals. Specific properties appear below.

ORTHOCLASE KAlSi_3O_8 - Colorless, white, gray, flesh red, or yellowish; more rarely greenish. H, 6; G, 2.6. Vitreous luster. Fusible with difficulty. Insoluble in acids. Often contains sodium. Very common rock forming mineral, occurring in igneous rocks of acidic or intermediate composition. Often shows penetration twinning. Used in porcelain.

MICROCLINE - Color, white, yellowish, gray, green or red. Chemical properties and occurrence same as for orthoclase. Much of what passes for orthoclase is really microcline.

Use same as orthoclase. Amazon stone is a bright green variety, used for gems.

PLAGIOCLASE FELDSPARS - These form a continuous series from albite (soda plagioclase), to anorthite (lime or calcic plagioclase). It is usually impossible to completely differentiate between plagioclases without a microscope. Minerals having compositions within certain limits between the two end minerals are called by specific names, as follows:

	Percent Albite	Percent Anorthite
Albite $\text{NaAlSi}_3\text{O}_8$ (Ab)	100-90	0-10
Oligoclase	90-70	10-30
Andesine	70-50	30-50
Labradorite	50-30	50-70
Bytownite	30-10	70-90
Anorthite $\text{CaAl}_2\text{Si}_2\text{O}_8$ (An)	10-0	90-100

Albite - Usually colorless or gray; rarely colored. H, 6 to 6.5; G, 2.6. Characteristic striations caused by albite twinning. Brittle. Vitreous luster. Transparent to subtranslucent. Fusible with some difficulty to colorless or white glass. Insoluble.

Anorthite - Color white, gray, reddish. H, 6 to 6.5; G, 2.75 (heavier than albite). Transparent to translucent, striations. Fusible with more difficulty than albite to colorless glass. Decomposed by hydrochloric acid with separation of gelatinous silica.

Intermediate plagioclases - Exhibit qualities between those of albite and anorthite. Labradorite sometimes has shimmering blue color (named labradorecence). All show striations to some extent.

Ferberite FeWO_4 (See Wolframite)

Color and streak, brown to black. H, 5 to 5.5; G, 7.5. Perfect cleavage in one direction. Crystals, also in compact and granular masses. Usually contains manganese and passes over into wolframite. Bright metallic luster. Occurs in quartz veins. Source of tungsten and its compounds.

Fluorite (Fluor Spar) CaF_2

Color varies widely; greenish, yellowish, or bluish in color; also various shades of red or brown, white and colorless. Sometimes multicolored. H, 4; G, 3.2. Vitreous luster. Transparent to translucent. Excellent octahedral cleavage. Frequently strongly fluorescent; sometimes phosphorescent when heated or exposed to electric discharges. Usually almost pure. Occurs in excellent cubic crystals, cleavable, granular, or columnar masses. Found in veins in limestones and dolomites, less frequently in granitic rocks and sandstones. Common gangue mineral with ores of lead, silver, copper and especially tin. Common associates are galena, sphalerite, cassiterite, calcite, quartz, barite, pyrite, topaz, tourmaline, and apatite. Used in the manufacture of open-hearth steel, enamel ware, glass, hydrofluoric acid, and in the electrolytic refining of antimony and lead.

Franklinite (Fe, Mn, Zn) $(\text{FeO})_2$

Color, iron black. Streak, reddish brown to black. H, 5.5 - 6.5; G, 5.5-2. Metallic to dull luster. Opaque. Rarely in octahedral crystals; usually granular compact masses or in grains. Imperfect octahedral cleavage. Conchoidal fracture. Brittle. Slightly magnetic, becoming stronger on heating. Infusible. Differentiated from magnetite by magnetism, streak, and zinc test. Associated with willemite, zincite and calcite. Found in quantity only at Franklin Furnace, N.J.

Galena PbS (86.6% Lead)

Color, lead gray. Streak, grayish black. H, 2.5; G, 7.4 to 7.6. Metallic luster, especially on cleavage surfaces, otherwise duller. Perfect cubical cleavage. Well-developed crystals common. Also in cleavable masses. Often contains small amounts of silver, therefore an important source of silver. Curved faces indicate other metals, notably silver, but

antimony, iron, zinc, gold, or bismuth may also be present. Alters to cerussite and anglesite. In veins or as fillings and replacements in limestones, almost always with sphalerite, also with various silver ores, quartz, calcite, and barite. Chief source of metallic lead.

Garnet Group

Garnet is a general name for any of a group of six minerals: Grossularite $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$, Pyrope $\text{Mg}_3\text{Al}_2(\text{SiO}_4)_3$, Spessartite $\text{Mn}_3\text{Al}_2(\text{SiO}_4)_3$, Almandite $\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$, Uvarovite $\text{Ca}_3\text{Cr}_2(\text{SiO}_4)_3$, Andradite $\text{Ca}_3\text{Fe}_2(\text{SiO}_4)_3$.

Color, commonly red, brown, yellow, green, or black; less frequently white or colorless. Light colored garnets are generally transparent to translucent, dark-colored varieties translucent to opaque. H, 6.5 to 7.5; G, 3.5 to 4.2. Vitreous to resinous luster. Indistinct cleavage. Generally well crystallized but occurs also as rounded disseminated glassy grains and in compact granular aggregates. Generally fuse with difficulty to a brownish or black glass, fused iron bearing garnets become magnetic, uvarovite almost infusible. Garnets alter readily to other minerals, especially chlorite, serpentine and talc. Garnet is a very common and widely distributed mineral. Occurs in crystalline schists as a contact metamorphic mineral, with various ores and in some igneous rocks. Common in placer concentrates where it is known as "ruby sand." Crushed and used as abrasives.

Gold (Native Gold) Au Usually 70% - 90% Gold, Remainder Mostly Silver

Color, golden yellow in various shades depending on amount of silver present. H, 2.5 to 3; G, 15.6 to 19.3 when pure. Metallic luster. Opaque. Very malleable and ductile. No cleavage. Crystals very rarely found. Usually in disseminated masses or scales or grains, some of which are very fine, also in large lumps or nuggets. Generally contains varying amounts of silver (up to 40 percent); also traces of iron, copper, bismuth, and others. Fuses fairly easily, insoluble in single acid, soluble in aqua regia and in chlorine and potassium or sodium cyanide. Forms amalgam with mercury. Occurs widely distributed in sparse amounts making it good for medium of exchange. Occurs in place and in secondary deposits, called placers. Gold in place is usually disseminated in quartz veins and associated with various sulfide minerals, of which pyrite is the most important. Also found disseminated in bedrock. The most common associates, aside from quartz and pyrite, are chalcopyrite, galena, stibnite, tetrahedrite, sphalerite, arsenopyrite, tourmaline and molybdenite. Used chiefly for coinage and jewelry.

Graphite C 100% Carbon Minus Impurities

Color dark gray to black. Streak shiny black. H, 1 to 2; G, 2.1. Marks paper and soils fingers. Metallic luster, sometimes dull or earthy. Perfect basal cleavage, yielding very thin and flexible scales. Greasy feel. Opaque. Good conductor of electricity. Usually found in foliated, scaly, granular, compact, or earthy masses. On combustion may yield as much as 20 per cent ash. Not attacked by acids. Distinguished from molybdenite by color, streak, and chemical tests. Infusible. Occurs in large masses and disseminated scales, also in dikes and veins in granites, gneisses, mica schists, and crystalline limestones. Used in manufacture of crucibles, lead pencils, points, lubricants, and electrodes.

Gypsum $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$

Colorless, white, gray, yellow, brown, reddish, or black. H, 2; G, 2.3. Vitreous to pearly or silky luster. Transparent to translucent. Common in cleavable, columnar, granular, fibrous, foliated, or earthy masses. Often mixed with clay, sand or organic matter. Yields water when heated and becomes white and opaque. Gypsum is common, often occurs in extensive deposits of great thickness. Usually found in evaporite salt deposits, frequently of great commercial importance. Common associates are halite, celestine, sulfur, dolomite, calcite, pyrite, and quartz. Used in plaster and as a fertilizer. Alabaster is fine grained massive gypsum used for statues, vases, etc. Satin Spar is fibrous gypsum. Selenite is the cleavable variety of gypsum.

Halite (Common Salt) NaCl

Colorless or white; when impure often reddish, blue, gray greenish, or black. The color may be unevenly distributed. Excellent cubical cleavage. H, 2.5; G, 2.1. Vitreous luster. Transparent to translucent. Crystals are generally cubes. Easily soluble in water. Saline taste. Colors flame intensely yellow. Halite occurs very widely distributed, chiefly as an evaporite deposit. Used extensively for household and industrial purposes.

Hematite Fe_2O_3 (70% Iron) Red Earthy Variety Known As Red Ochre

Color, reddish brown to black. Cherry red or reddish brown streak. H, 5.5 to 6.5; earthy varieties are very soft; G, 4.9 to 5.3 (for crystals). Metallic luster in crystals or dull in earthy varieties. Opaque, except in very thin scales. Conchoidal to uneven fracture. Sometimes slightly magnetic due to the presence of small amount of magnetite. Most often earthy, also botryoidal (kidney ore), micaceous (specularite) oolitic, fossiliferous. Thin plates often arranged in rosettes called iron roses. May contain titanium and magnesium. Infusible. Becomes magnetic when heated in reducing flame. When powdered, it is slowly soluble in acids. Occurs as a pseudomorph after calcite, siderite, pyrite, and magnetite. Hematite is very widespread. Occurs as independent deposits of tremendous size, as an accessory mineral in many igneous rocks, as a sublimation product in lavas, in contact metamorphic zones, and in many other ways. Chief source of iron of commerce and industry. About 90 percent of the iron ore mined annually is hematite.

Hemimorphite $\text{Zn}_4\text{Si}_2\text{O}_7(\text{OH})_2 \cdot \text{H}_2\text{O}$

(This is sometimes called "calamine" in U. S. This practice should be discontinued, inasmuch as "calamine" is used in Britain for smithsonite).

Color, white, brown, green, or bluish. H, 4.5 to 5; G, 3.4 to 3.5. Transparent to opaque. Vitreous luster. Prismatic cleavage. Uneven to conchoidal fracture. Usually crystalline. Often arranged in sheaflike or crested groups. Also fibrous, globular, granular masses. Almost infusible. Gelatinizes easily with acids. Zinc tests. Water in closed tube. Occurs as a pseudomorph after calcite, galena, dolomite, and fluorite. Hemimorphite is a secondary mineral, formed by the action of silica bearing water upon other zinc ores, and is usually found in limestones associated with smithsonite, sphalerite, galena, cerussite, and anglesite. An important ore of zinc.

Hornblende Complex Silicate Of Ca, Mg, Fe, Al, F, (OH)

This is the most common member of the amphibole group. The amphiboles are a group of dark, rock forming minerals - compare augite. Color, usually dark green, brown, or black. Streak, grayish green to grayish brown. H, 5 to 6; G, 3.2. Vitreous luster, fibrous variety silky. Translucent to opaque. Perfect prismatic cleavage on angles of 56° and 124° . Crystals common. Occurs also in bladed, fibrous, columnar, granular, or compact masses. Fusible with difficulty. A small amount of water is present which tends to distinguish hornblende from augite; hornblende yields water. Alters to chlorite, epidote, calcite, siderite, and limonite. Hornblende is a very common constituent of igneous and metamorphic rocks. Tends to occur with the light colored intermediate rocks rather than the darker ones with which augite occurs. (See Chapter 3 for more distinguishing features.)

Huebnerite MnWO_4 (See Wolframite)

Huebnerite is at the manganese end of the mineral series huebnerite-wolframite-ferberite. Color, brownish, red, brownish black, or nearly black in color; in transmitted light pale ruby red to yellow. Streak yellow to yellow brown. H, 4.5 to 5.5; G, 7. Submetallic to resinous luster. Translucent to opaque. Generally in long fibrous, bladed, or stalky crystals. Also in compact, lamellar, or cleavable masses. Usually contains iron and grades into wolframite. Occurs in high temperature quartz veins with wolframite, fluorite, scheelite, cassiterite, and other high temperature minerals. A source of tungsten.

Ilmenite (Titanic Iron Ore) FeTiO_3

Color, iron to brownish black. Streak black to brownish red. H, 5 to 6; G, 4.7. Metallic to submetallic luster. Opaque. Conchoidal to uneven fracture. May be slightly magnetic, greatly increased by heating. Crystals resemble those of hematite. Generally in compact or granular masses, also in thin plates of disseminated grains, or as pebbles or sand. Distinguished from hematite by streak; from magnetite by intensity of magnetism. Magnesium or manganese may replace some of the iron. Infusible. An accessory mineral common in many igneous and metamorphic rocks. Common associates are hematite, magnetite, apatite, serpentine, titanite, rutile. Not used as an ore of iron, but as a source of titanium. Used in preparation of puddling furnace linings and in making paint. Sands containing ilmenite, cassiterite, rutile and magnetite are termed black sands.

Jade

Jade is a jewelers' term, covering several semi-precious or precious green to white stones.

There are, however, only two true jade minerals, jadeite, a pyroxene, and nephrite, an amphibole.

JADEITE $\text{Na Al Si}_2\text{O}_6$ - Color apple to emerald green, occasionally white. H, 6.5 to 7, G, 3.4. Very tough. Translucent. Fuses readily to transparent blebby glass, which distinguishes it from nephrite. Splintery fracture. Cleavage angle of pyroxene (87° and 93°).

NEPHRITE - Color white to dark green. H, 6 to 6.5; G, 3. Tough. Splintery fracture. Fine grained, massive. Nephrite varies in composition between tremolite, in which case it is white, to actinolite, green. Cleavage angles of amphibole (56° and 124°).

Jamesonite (Brittle Feather Ore) $\text{Pb}_4\text{FeSb}_6\text{S}_{14}$ (29.5% Antimony; 50.8% Lead)

Color steel gray to dark lead gray. Streak grayish black. H, 2 to 3; G, 5.5 to 6. Metallic luster. Perfect basal cleavage. Fracture uneven to conchoidal. Brittle. Opaque. Very easily fusible. Lead and antimony tests. In needlelike crystals, feathery in appearance, also fibrous massive; compact massive. Most varieties show a little iron (1 to 3 per cent) and some contain also, silver, copper, and zinc. In veins formed at moderate to low temperatures, associated with other lead minerals; galena, stibnite, tetrahedrite, sphalerite, pyrite, commonly in quartz with siderite, dolomite, rhodochrosite, and calcite. Minor ore of lead.

Kaolinite $\text{H}_4\text{Al}_2\text{Si}_2\text{O}_9$

Kaolinite is one of several clay minerals composing kaolin a white high grade china clay. Color, white, often shaded by impurities. Streak, white to yellowish. H, 2 to 2.5; G, 2.6. Compact masses dull, scales pearly in luster. Greasy feel. Opaque to translucent. Usually plastic when moistened. Argillaceous odor when breathed upon. Scales possess a basal cleavage. Earthy fracture. Adheres to tongue. Generally in compact, friable, mealy, or clay-like masses. Yields water on ignition. Infusible. Insoluble. Always a secondary mineral resulting from alteration by hydrothermal action or weathering of rocks containing aluminum silicates, especially feldspar. In irregular deposits in hydrothermally altered (kaolinized) rocks, or in residual or transported weathering deposits. Used in ceramics.

Leucite $\text{K Al(SiO}_3)_2$

Leucite is a feldspathoid and cannot exist in the presence of much free quartz. Color white or light gray. H, 5.5 to 6; G, 2.5. Conchoidal fracture. Vitreous to greasy luster. Translucent to opaque. In crystals, rounded grains, rarely in granular masses. Crystals sometimes striated. Infusible. Decomposed by hydrochloric acid. Occurs only in igneous rocks, usually lavas.

Limonite Approximately $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$ (59.9% Iron)

Limonite is a mixture of goethite and certain other iron minerals. Color, yellow, brown, or black. Streak always yellow brown. H, 5.5, much softer (as low as 1) in earthy varieties; G, 3.4 to 4. Conchoidal to earthy fracture. Nearly always found in compact, porous, or earthy masses. Sometimes exhibits fibrous structure and black, varnish-like surfaces. Luster submetallic to dull. May also contain silica, clay, manganese oxide, and organic matter. Is the usual weathering product of iron minerals and is found very extensively, usually in association with iron bearing ore minerals, and also with many of the rock-forming minerals that contain iron in small quantities. It is the rusty iron material to which metallic sulfides weather. Constitutes about 4 percent of the iron ore mined in the U. S. Also used in paints as yellow ochre, umber, and sienna, depending on amount of manganese present.

Magnesite MgCO_3

Color, white, yellow, brown, or blackish. H, 3.5 to 5; G, 3.2. Vitreous to dull luster. Crystals have rhombohedral cleavage. Brittle. Transparent to almost opaque. Usually in granular, compact, or earthy masses with the appearance of unglazed porcelain. Sometimes in cleavable masses, rarely coarsely crystalline, resembling coarse dolomite or marble in texture. Iron may substitute for magnesium. Calcium may be present. Infusible. Powdered magnesite is soluble with effervescence in hot dilute acids. Found in veins in schists and in serpentine, and as beds in limestone and dolomite. Used chiefly in the manufacture of refractories and as a source of magnesium compounds.

Magnetite (Magnetic Iron Ore; Fe}_3\text{O}_4 (72.4% Iron)

If it will act as a magnet, called lodestone. Color, iron black. Streak black. H, 6; G, 4.9 to 5.2. Metallic to submetallic luster. Opaque. Strongly magnetic. Octahedral parting.

Conchoidal to uneven fracture. Fuses with difficulty. Crystals very common. Usually occurs in coarse to fine-grained masses, in lamellar to compact aggregates, as disseminated grains, or as loose grains or sand; more rarely dendritic, especially in mica. May contain magnesium, nickel, manganese, phosphorus, or titanium. Alters to limonite and hematite. Occurs as a pseudomorph after pyrite, hematite, and siderite. Widespread, found principally as 1) a primary constituent of basic igneous rocks, 2) as a metamorphic mineral; and 3) as a constituent of certain river, lake and marine sands, called black sands. Common associates are hornblende, augite, feldspar, quartz, pyrite, chalcopyrite, epidote, chromite, garnet, and ilmenite. Impartant iron ore.

Malachite (Green Carbonate Of Copper) $\text{CuCO}_3 \cdot \text{Cu(OH)}_2$ (57.4% Copper)

Color, bright green. Streak, paler green. H, 3.5 to 4; G, 3.9 to 4.1. Adamantine to vitreous, silky in fibrous, dull in earthy varieties. Conchoidal to splintery fracture. Translucent to opaque. Commonly in botryoidal masses with smooth surfaces and a banded or radial fibrous structure; also earthy and in velvety crusts. Malachite is a common alteration product of copper minerals, found to some extent in the upper levels of all copper mines. Commonly associated with other copper minerals. It is the only vivid green carbonate. Important ore of copper. Also used in jewelry and for ornamental purposes.

Manganite $\text{Mn}_2\text{O}_3 \cdot \text{H}_2\text{O}$ (62.4% Manganese)

Color, iron black or dark gray; streak dark brown. Metallic to submetallic luster. H, 3.5 to 4; G, 4.3. Uneven fracture, opaque. Prismatic crystals deeply striated, radial fibrous and columnar masses, more rarely granular and stalactitic. Infusible. Soluble in concentrated hydrochloric acid with an evolution of chlorine. Water in closed tube, manganese tests. Alters easily to pyrolusite. Commonly associated with pyrolusite and other manganese minerals, and hematite, barite, and calcite. A minor ore of manganese. With pyrolusite, it is used in preparation of oxygen and chlorine.

Marcasite (White Iron Pyrites) FeS_2

Color, pale bronze yellow to steel gray, darker after exposure. Usually lighter in color than pyrite. Streak grayish black. H, 6 to 6.5; G, 4.9. Metallic luster. Opaque. Crystals usually tabular or short columnar; arranged to give spear-shaped or "cockscorn" structure. Also stalactitic, reniform, and globular, often with radial structure. Brittle. Easily fusible to magnetic globule. Arsenic sometimes present. Alters more readily than pyrite, forming limonite. Powdered marcasite dissolves in concentrated nitric acid, and upon boiling, sulfur separates out; pyrite treated similarly dissolves completely. Not so abundant as pyrite. When massive, difficult to distinguish from pyrite. Frequently in veins, especially of lead and zinc ores, and as secondary mineral in sedimentary rocks. Used to minor extent in manufacture of sulfuric acid.

Mica Group (See Biotite, Muscovite, And Phlogopite)

A group of related minerals whose outstanding characteristic is highly perfect cleavage in one direction. The more common representatives are muscovite, biotite, lepidolite and phlogopite. These are true micas. Minerals such as vermiculite, chlorite, talc, and serpentine, although not true micas, have certain similar characteristics.

Molybdenite MoS_2 (59.9% Molybdenum)

Color blue gray (graphite is black). Greenish gray streak on glazed porcelain (graphite shiny black). H, 1 to 1.5; G, 4.7. Excellent basal cleavage. Flexible but not elastic. Greasy feel. Marks paper. Molybdenum tests. Generally in disseminated scales or grains; sometimes in foliated or granular masses. Usually disseminated in granites or pegmatites. Also in tin ore deposits and contact deposits and high temperature quartz veins. Commonly with cassiterite, wolframite, topaz, epidote, and chalcopyrite. Chief source of molybdenum and its compounds.

Monazite (Phosphate Of Rare Earths: Cerium, Lanthanum, Thorium, Yttrium, Neodymium)

Color, brownish gray, amber, yellow, or reddish. Streak, white. H, 5 to 5.5; G, 4.9 to 5.3 (heavy for non metallic mineral). Resinous luster. Translucent. Conchoidal fracture. Brittle. Crystals not common. Generally found as angular disseminated masses and as rolled grains in sand. Infusible, insoluble in hydrochloric acid. Gives phosphate test. May contain 0.5 to 12 percent ThO_2 ; commercial monazite sand contains usually from 2.5 to 5 percent. Occurs disseminated as accessory mineral in granites and gneisses, pegmatites. Most important

occurrence of monazite is as sand in placers. Common associates are magnetite, zircon, garnet, ilmenite, thorite, gold, chromite, and sometimes diamond. Chief source of thorium dioxide which is used in the manufacture of incandescent mantles. Also source of cerium oxide.

Muscovite (White Mica) $\text{KAi}_2(\text{OH})_2\text{AlSi}_3\text{O}_{10}$ Approximately

Colorless in thin sheets, yellowish, brownish, reddish, in thicker blocks. H, 2 to 3; G, 2.8 to 3.1. Vitreous to pearly luster. Highly perfect basal cleavage permitting very thin, transparent, and elastic leaves to be split. Transparent to translucent. Crystals often large and rough. Usually in scaly or foliated aggregates. Fuses with difficulty to a grayish or yellowish glass. Not attacked by common acids; water in closed tube. Muscovite generally considered the most common mica, occurs in acid igneous rocks, pegmatite dikes and metamorphic rocks. When in minute scales called *sericite*. Very widespread. Used principally as electrical insulation. Transparent sheets used for windows in stoves, (isinglass). Scrap mica is ground and used in the manufacture of wall paper, lubricants, paints, rubber goods, and roofing papers.

Nepheline (Nephelinite) $(\text{Na}, \text{K}) (\text{Al}, \text{Si})_2 \text{O}_4$

Colorless, white, yellow. H, 5.5 to 6; G, 2.6. Vitreous luster, greasy on cleavages. Transparent to opaque. Conchoidal to uneven fracture. Brittle. Compact masses or disseminated grains. Fuses to colorless glass. Sodium flame. Gelatinizes with acids. Occurs in igneous rocks, especially recent lavas. Nepheline is a feldspathoid, and cannot exist in the presence of much free quartz. Used in place of feldspar for ceramics.

Nicolite (Copper Nickel) NiAs (64.7% Nickel)

Color, pale copper red, tarnished gray to blackish. Streak brownish black. Uneven fracture. H, 5 to 5.5; G, 7.3 to 7.8. Metallic luster. Opaque. Easily fusible. Nickel and arsenic tests. Nearly always very fine grained, massive, also reniform with columnar structure. May contain small amounts of iron, cobalt, and sulfur; arsenic sometimes replaced by antimony. Associated with nickel, cobalt, and silver ores, also pyrrhotite, chalcopyrite; sometimes in or near norite rocks. Quickly alters to light green "nickel bloom" (annabergite), which forms coating. Minor ore of nickel.

Olivine $(\text{MgFe})_2\text{SiO}_4$

Olive to grayish green, brown. H, 6.5 to 7; G, 3.3 to 3.6. Vitreous luster. Transparent to translucent. Granular, sugarlike texture. Infusible. Common rock forming mineral, found in basic to ultrabasic rocks. The rock *dunite* is almost wholly olivine. Alters easily to serpentine. Never found with quartz. Transparent green variety is *peridot*, used as gem.

Opal $\text{SiO}_2 \cdot n\text{H}_2\text{O}$

Color varies greatly; colorless, white, shades of yellow, brown, red, green, gray, blue. Opalescent, often a fine play of colors observed. Sometimes luminescence. Streak white. H, 5 to 6; G, 1.9 to 2. Vitreous, sometimes inclines to resinous or pearly. Conchoidal fracture. Transparent to nearly opaque. Always amorphous. Usually compact, sometimes botryoidal, stalactitic. Water may vary from 1 to 21 percent, usually between 3 and 13 percent. Yields water when intensely heated in a closed tube. Infusible. Insoluble. Commonly deposited in cracks and cavities in igneous and sedimentary rocks by hydrothermal solutions, also around hot springs and in skeletons of minute animals. Sometimes replaces wood. Many varieties; precious opal has internal play of colors. Fire opal has red reflections, common opal, widespread, geyserite, deposited around hot springs, wood opal, replacing wood, diatomite, accumulated skeletons, hyalite, clear opal with botryoidal surface. Used as gems; diatomite as abrasive and filler.

Orpiment As_2S_3

Color and streak, lemon yellow. H, 1.5 to 2; G, 3.5. Resinous to pearly luster. Plates flexible but not elastic. Sectile. Translucent. Arsenic tests. Indistinct small tabular crystals; usually in foliated or columnar masses. Good cleavage in one direction. Rare, found with realgar and ores of silver and antimony, and as a sublimation product from hot springs. Not important commercially. The artificial compound is used as a pigment and in dyeing and tanning.

Pentlandite $(\text{Fe}, \text{Ni})\text{S}$

Color, light bronze-yellow. Streak light bronze-brown. H, 3.5 to 4; G, 5. Metallic

luster. Octahedral parting. Fracture uneven. Brittle. Opaque. Easily fusible. Magnetic on heating. Nickel and iron tests. Massive, granular. Almost always occurs intergrown with pyrrhotite and associated also with niccolite, pyrite, marcasite, and chalcocopyrite. "Nickeliferous pyrrhotite" contains pentlandite. Principal ore of nickel.

Phlogopite (Bronze Mica, Amber Mica) $\text{KMg}_2\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_2$ Approximately

Color, yellowish brown, green, white, sometimes copperlike reflections. Thin sheets are transparent. H, 2.5 to 3; G, 2.8. Pearly to submetallic luster. Highly perfect basal cleavage. Thin layers tough and elastic. Crystals sometimes large and coarse. In disseminated scales, plates, or aggregates. Whitens and fuses on thin edges. Water in closed tube. Insoluble in hydrochloric acid but decomposed in boiling concentrated sulfuric acid, giving milky solution. Occurs in crystalline limestones, metamorphic rocks, dolomites, serpentine. Used as insulator in electrical apparatus.

Pitchblende (When Crystalline Called Uraninite) UO_2 to $\text{U}_3\text{O}_8 + \text{Pb}$ And Rare Elements

Color, brown to black. Streak, dark green, brown, or black. H, 5.5; G, 9 to 9.7 in crystalline forms. Pitchy to submetallic luster on fresh fracture surfaces, otherwise dull. Conchoidal to uneven fracture. Strongly radioactive. Commonly in compact, reniform, curved lamellar, or granular masses. Composition uncertain. May also contain radium. Found as a constituent of pegmatites and granites, and in veins. Alters to green and yellow secondary uranium minerals. Important source of uranium and radium compounds.

Platinum (Native Platinum) $\text{Pt} + \text{Platinum Group Elements}$

Color, light steel gray to dark gray. H, 4.5; G, 15 to 19, 21 if pure. Metallic luster. Opaque. Malleable, ductile. May be magnetic if much iron is present. Usually in scales, grains, or nuggets. Native platinum usually contains iron (up to 19.5 percent) and smaller amounts of iridium, rhodium, palladium, osmium, copper, and at times, gold. Infusible with blowpipe. Soluble in hot concentrated aqua regia. Practically all of the world's supply obtained from placer deposits, or as by-product of nickel mines. Also occurs in segregations with chromite in ultrabasic rocks. Used as a catalytic agent in the petroleum industry and in the manufacture of acids, and in chemical and electrical apparatus; also in jewelry, dentistry, and surgical instruments.

Proustite (Light Ruby Silver) Ag_3AsS_3 (65.4% Silver)

Color and streak, scarlet to vermillion. Surface tarnish black. H, 2 to 2.5; G, 5.5. Adamantine to dull luster. Conchoidal to uneven fracture. Translucent, transparent to red light. Generally massive, compact, or disseminated. May contain antimony. Very easily fusible to silver globule with soda on charcoal. Decomposed by nitric acid, with separation of sulfur. Arsenic and silver tests. Occurs with pyargyrite in veins with other silver minerals, galena, tetrahedrite, sphalerite. Ore of silver.

Psilomelane $\text{H}_4\text{Ba}_2\text{Mn}_6\text{O}_{20}$ Approximately

Color dark gray to iron black. Brownish black streak. H, 5 to 6; G, 3 to 4.5. Dull or submetallic luster. Opaque. Occurs usually in compact or earthy or colloform masses without crystalline structure. Composition varies greatly: MnO_2 , 70 to 90 percent; BaO , 6 to 18 percent; H_2O , 1 to 6 percent. It may also contain potassium, calcium, copper, silicon, and iron. Infusible. Much water in closed tube. Evolves chlorine when treated with hydrochloric acid. Manganese tests. A secondary mineral usually associated with other manganese minerals, limonite, or barite. Ore of manganese.

Pyargyrite (Dark Ruby Silver) Ag_3SbS_3 (59.9% Silver)

Color, dark red to black, translucent red on thin edges. Streak cherry to purple red. Turns black when exposed to light. H, 2.5; G, 5.8. Metallic-adamantine luster. Conchoidal fracture. Very easily fusible; silver and antimony tests. Usually massive-compact, disseminated crusts or bands in veins. May contain a little arsenic. Resembles proustite but more abundant. Deeper red and less translucent than proustite. Found in low temperature veins with other silver ores, calcite, and galena. Important ore of silver in certain places.

Pyrite (Iron Pyrites, Fools' Gold) FeS_2

Color, pale brassy to golden yellow, sometimes with brown or variegated tarnish colors.

Streak greenish to brownish black. H, 6 to 6.5; G, 4.9 to 5. Metallic luster. Uneven fracture. Brittle. Opaque. Crystals commonly showing striations. Cubes, pyritohedrons (having five sided faces) and octahedrons common. Also massive and disseminated. Decomposes readily, especially in a moist atmosphere, to limonite, iron sulfates and sulfuric acid. Fuses to magnetic globule. Iron tests. Pseudomorphs of limonite after pyrite common. Pyrite is most common sulfide mineral and found very widely distributed. Mode of occurrence varies greatly, may be associated with almost any mineral. Occurs in rocks of all types and ages, especially metamorphic and sedimentary. Commonly found in veins, as nodules and concretions in slates, sandstones, and coals. Used principally as source of sulfuric acid.

Pyrolusite MnO_2 (60-63% Manganese)

Black or dark steel-gray color. Black or bluish black streak. H, 1 to 2; G, 4.8. Usually stains fingers. Metallic to dull luster. Opaque. Prismatic and needle-like. Compact, fibrous, columnar, stalactitic, dendritic, or powdery crusts. Usually contains small amounts of water and silica. Manganese tests. Secondary mineral resulting from decomposition of manganite, rhodochrosite, and manganiferous iron ores. Associated with manganite, psilomelane, hematite, or limonite.

Pyrrhotite (Magnetic Pyrites) $Fe_{1-x}S$

Color, bronze yellow to bronze red. Quickly tarnished to dirty brown. Streak grayish black. H, 3.5 to 4; G, 4.6. Metallic luster. Opaque. Inferior basal cleavage. Masses frequently magnetic; powder magnetic. Usually massive, granular. Contains excess sulfur. Nickel often present, probably as enclosed grains of pentlandite and commonly associated with pyrite, chalcopyrite, pentlandite, magnetite, etc. Important source of nickel.

Quartz SiO_2

Colorless when pure, white, yellow, red, pink, green, blue, brown and black. Many colors disappear on heating. H, 7; G, 2.6. Vitreous luster. Indistinct rhombohedral cleavage. Conchoidal fracture. Transparent to opaque. Some varieties may show luminescence. Hexagonal crystals very common. Commonly found in distinct crystals, also occurs in a great variety of massive forms. Often contains inclusions of hairlike rutile, or hematite, chlorite, mica and liquid and gaseous carbon dioxide. Infusible; insoluble. Common as a pseudomorph after fluorite, calcite, siderite, and wood. Next to water, is most common of all oxides. Very important rock-forming mineral, constituent of many igneous and sedimentary rocks. Occurs in rocks of all ages and as gangue in many ore deposits. Also found very abundantly as sand and gravel. Some varieties used in jewelry and for ornamental purposes, optical instruments, radio crystals, building and paving, grindstones and abrasives, flux in metallurgical processes. Different colored varieties called by special names: Rock crystal, clear; Amethyst, blue, violet; Rose, pink; Citrine, yellow; Smoky quartz, gray; Milky, white, etc.

Realgar As_2S_3

Color, aurora-red to orange-yellow. Streak, orange, orange red. H, 1.5 to 2; G, 3.5. Resinous luster. Conchoidal fracture. Transparent to translucent. In closed tube melts to dark red liquid when hot, reddish yellow solid when cold. Arsenic tests. Crystals are usually short, prismatic. Also in granular and compact masses and incrustations and coatings. Alters to orpiment. Occurs with ores of silver and antimony and usually associated with orpiment. Also as a sublimation product and as a deposit from hot springs. No present economic importance.

Rhodochrosite $MnCO_3$ (47.5% Manganese)

Color, usually rose red or pink, also gray, dark brown. H, 3.5 to 4.5; G, 3.4 to 3.6. Vitreous to pearly luster. Perfect rhombohedral cleavage. Uneven fracture. Brittle. Translucent. Generally in cleavable or granular masses; also botryoidal with columnar structure, incrustations. Frequently curved faces. Iron often present replacing the manganese. Infusible, soluble in hot hydrochloric acid with effervescence. Manganese tests. Occurs as a pseudomorph after calcite and fluorite. Usually found in veins with ores of lead, silver, and copper, and other manganese minerals. Most common associates are galena, sphalerite, pyrite, rhodanite, and psilomelane. Not common. Sometimes used as a source of manganese and its compounds.

Rhodonite $MnSiO_3$ (41.9% Manganese)

Color, rose red, pink, yellowish, greenish, or brownish, often black externally (oxide

stain). H, 5.5 to 6; G, 3.4 to 3.7. Vitreous to pearly luster. Prismatic and basal cleavages. Conchoidal to uneven fracture. Transparent to opaque. Generally in fine grained, cleavable, or compact masses; also in disseminated grains. Commonly contains some calcium and iron. Fuses easily to brownish or black glass. Slightly attacked by acids, although varieties containing an admixture of calcite will effervesce. Occurs in high temperature veins and in crystalline limestones. Occurs with garnet, calcite, rhodochrosite, and other manganese minerals, and with iron ores. Sometimes used for gem and ornamental purposes. Distinguished from rhodochrosite by hardness and insolubility.

Rutile TiO_2 (60% Titanium)

Color, red, brown or black. Streak, pale brown; when oxidized, streak dark gray to black. H, 6 to 6.5; G, 4.2. Metallic-adamantine luster. Distinct prismatic and pyramidal cleavages. Sometimes striated. Opaque to transparent. Crystals common, also in compact granular masses. Infusible, insoluble. Titanium tests. Hair-like crystals of rutile occur frequently as inclusions in quartz (rutilated quartz). Usually contains iron. Occurs as pseudomorph after hematite. Rutile is the most common titanium mineral. Occurs as accessory mineral in granite, mica, schist, metamorphic limestone, and dolomite, or in quartz veins. Commonly associated with quartz, hematite, and feldspar; also in placer concentrates. Used as source of titanium.

Scheelite $CaWO_4$ (80.6% WO_3 , Tungsten Trioxide)

Color, white, yellow, brown, green, or reddish. H, 4.5 to 5; G, 5.9 to 6. Adamantine to greasy luster. Distinct pyramidal cleavage. Conchoidal to uneven fracture. Transparent to opaque. Crystals generally small. More often as crystalline crusts on quartz, or in reniform, disseminated, or granular masses. Usually contains some molybdenum. Fusible with difficulty. Tungsten tests. Quickest test is fluorescence. Occurs as a pseudomorph after wolframite. Usually found with high temperature mineral, quartz, cassiterite, fluorite, topaz, molybdenite, wolframite, and apatite. An important source of tungsten and its compounds.

Serpentine $Mg_3Si_2O_5(OH)_4$

Color, various shades of green, rarely yellowish, grayish, reddish, brownish, or black. H, 2 to 5; G, 2.2 to 2.6. Dull, resinous, greasy, waxy, or silky luster. Conchoidal to splintery fracture. Often spatted, clouded or multicolored. Smooth to greasy feel. Platy serpentine is antigorite; fibrous, chrysotile. Varieties:

COMMON SERPENTINE - Compact, massive. Generally dark in color, rock often multicolored. Very abundant, forms the rock serpentinite.

PRECIOUS SERPENTINE - Massive, various shades of green, sometimes yellowish. Translucent.

CHRYSOTILE, FIBROUS SERPENTINE, ASBESTOS - delicate, fine, parallel fibers, which can be easily separated. Fibers flexible and adapted for spinning. Silky luster. Various shades of green, also white, yellowish, or brownish. Usually found in veins with the fibers perpendicular to the walls.

VERD ANTIQUE - serpentine mixed irregularly with calcite, dolomite, magnesite, or talc. Takes excellent polish and used extensively for ornamentation.

May contain iron and nickel. Yields water when ignited. Splinters fuse with difficulty. Decomposed by acids with separation of silica without formation of jelly. A secondary mineral resulting from the alteration of magnesium minerals and rocks, such as olivine, hornblende, augite. Polished massive serpentine and verd antique are used for ornamental purposes. Sometimes cut and polished for gem purposes. Asbestos used as heat insulator.

Siderite $FeCO_3$ (48.2% Iron)

Color, brownish to nearly black, also rarely gray, green, or white. Streak white or yellowish. H, 3.5 to 4; G, 3.7 to 3.9. Vitreous to pearly luster. Perfect rhombohedral cleavage. Conchoidal fracture. Translucent to nearly opaque. Distorted and curved or saddle shaped crystals are quite common. Usually found in cleavable, granular, or fibrous masses. Also botryoidal and earthy. Usually contains some $CaCO_3$ and $MnCO_3$. Difficultly fusible, soluble in hot hydrochloric acid with effervescence. Magnetic on heating. Iron tests. Occurs as a pseudomorph after calcite, dolomite, barite, and fluorite. Alters to limonite, hematite, and magnetite. Siderite occurs commonly with sulfide ore deposits, also in beds and as concretions in limestones and shales. The common associates are pyrite, chalcopyrite, galena, tetrahedrite. A minor ore of iron.

Sillimanite Group, Al_2SiO_5

Color, gray, brown, yellowish, or greenish. H, 6 to 7; G, 3.2 to 3.3. Vitreous or silky

luster. Uneven fracture. Transparent to translucent. Usually in long, thin, hairlike crystals or in radiating fibrous or columnar masses. Crystals are often bent, striated, interlaced or without sharp edges. Often impure. Infusible, insoluble. Aluminum tests. Alters to mica, kaolinite, or dense talcose-like minerals. Occurs as an accessory constituent of gneisses, quartzites, mica schists, and other metamorphic rocks. Sometimes associated with zircon or corundum. Andalusite, sillimanite, and kyanite, the members of the group, are identical in composition. At high temperature they convert to mullite, in which form they are used for spark plugs and other items requiring a highly refractory material. Characteristics of all three minerals generally similar. Andalusite slightly harder, H, 7.5. Coarsely prismatic. Color gray, greenish, reddish or bluish. Kyanite in long bladed columns. Color bluish, white, gray, green black. Hardness varies with face, from 4 to 7.

Silver (Native Silver) Ag (100% Silver Minus Impurities)

Color, silver white, often with yellow-brown, gray, or black tarnish. Streak, silver white, shiny. H, 2.5 to 3; G, 10 to 12 (10.5 when pure). Metallic luster. Malleable and ductile. Excellent conductor of heat and electricity. Hackly fracture. Easily fusible to bright globule. Found as fine threads or wires; scales, plates, or large masses. Native silver often contains varying amounts of gold (up to 28 percent), copper, mercury, more rarely traces of antimony, bismuth, platinum. Occurs with ores of silver, lead, copper, arsenic, cobalt, nickel and uraninite. Secondary mineral in oxidized zone or in primary deposits. It is found in large deposits, disseminated and in veins. Rarely found as nuggets. Used for coinage, jewelry, ornamental purposes and apparatus.

Skutterudite (Co, Ni, Fe) As₃

(The cobalt variety is called Smallite; the nickel variety is called Nickel Skutterudite, formerly Chloanthite). Color, tin-white to light steel gray. Tarnishes dull. Grayish blue streak. (May have a pink tinge). H, 5.5 to 6; G, 6.5. Metallic luster. Uneven fracture. Cleavage indistinct. Brittle. Opaque. Garlic odor. Usually massive-compact, granular, lamellar, or fibrous. Iron may amount to 18 percent causing higher specific gravity. Easily fusible; cobalt and arsenic tests. Usually with cobalt, nickel, and silver ores; also with native bismuth, barite, siderite, quartz. An important source of cobalt. Distinguished from arsenopyrite by non-crystalline character and cobalt tests.

Smithsonite (Dry Bone Ore) ZnCO₃

Color commonly dirty brown, also white, blue, green or pink; yellow variety (turkey fat ore) contains cadmium. Streak white. H, 4.5 to 5; G, 4.3 to 4.5. Rhombohedral cleavage (seldom observed). Uneven to splintery fracture. Vitreous to pearly luster. Translucent. Crystals usually small, rough, or curved. Usually reniform or botryoidal, also incrustations. Dry bone the cellular and porous variety. Iron, manganese, replace part of zinc, also calcium and magnesium may be present. Effervesces slightly in cold dilute acid. Infusible. Zinc tests. A secondary mineral occurring in the upper levels of mines in limestones and dolomites. Common as a pseudomorph after calcite. Common associates, sphalerite, hemimorphite, galena, limonite, and calcite. "Calamine" is name for smithsonite in Britain. Ore of zinc. Minor ornamental use.

Sodalite Na₄Al₃Si₃O₁₂Cl

Color blue, gray, greenish, yellowish, reddish, white. H, 5.5 to 6; G, 2.1 to 2.3. Transparent to translucent. Crystals, grains, masses, sometimes concentric nodules. A feldspathoid. Vitreous to greasy luster. Conchoidal fracture, brittle. Fuses with intumescence to clear glass. Soluble in hydrochloric acid. Occurs in igneous rocks of nepheline-syenite and related clans.

Sphalerite (Blende, Zinc Blende, Black Jack) ZnS (67% Zinc)

Color varies greatly; when pure, white; commonly yellow, red (ruby zinc), black (black jack or marmatite) or green. Streak white, pale yellow or brown. H, 3.5 to 4; G, 4. Resinous to submetallic or adamantine luster. Good cleavage unless fine grained. Brittle. Transparent to translucent. Fluorescence sometimes observed. Zinc tests. Crystals common, often distorted or rounded. Generally in cleavable, fine to coarse granular, and compact masses; also fibrous. Usually contains iron, up to 18 percent, also manganese, cadmium in small amounts. Occurs chiefly in veins and replacements and fillings in limestones. Usually associated with galena, chalcopyrite, pyrite, barite, fluorite. Almost always with galena. Commonly in veins and cavities.

Spodumene $\text{LiAl}(\text{SiO}_3)_2$

Color white, gray, red, pink, purple. Streak, white. H, 6.5 to 7; G, 3.2. Vitreous to pearly luster. Transparent to translucent. Prismatic crystals, sometimes striated. Also massive and cleavable. Fracture uneven to subconchoidal. Brittle. When heated with blowpipe, swells up and becomes white. Fuses to clear glass. Lithium flame color. Insoluble. Occurs in granite pegmatites, sometimes in crystals of great size (lengths of over 40 feet are known). Associated with beryl, tourmaline, garnet, lepidolite, feldspar, quartz. Used as source of lithia compounds, and as gems (hiddenite is a yellow or green variety; kunzite is lilac pink).

Stannite $\text{Cu}_2\text{FeSnS}_4$ (27.5 % Tin)

Color, steel gray to iron black, the former when pure; sometimes a bluish tarnish, often yellowish from presence of chalcopyrite. Streak, blackish. H, 4; G, 4.4. Metallic luster. Uneven fracture. Brittle, opaque. Twinned crystals. Also massive, granular, and disseminated. Easily fusible. Copper, iron and tin tests. Occurs in tin-bearing veins associated with cassiterite, chalcopyrite, tetrahedrite, and pyrite. Often contains various of these and other minerals as inclusions. Minor ore of tin.

Staurolite $\text{FeAl}_4\text{Si}_2\text{O}_{10}(\text{OH})_2$

Color red brown to reddish black. Colorless streak when fresh. H, 7 to 7.5; G, 3.7. Resinous to vitreous luster, dull or earthy when impure. Translucent. Usually in crystals. Prismatic habit, rarely massive. Often twinned to form crosses. Infusible, insoluble. Yields little water on intense ignition. Crystals and twins most characteristic. Accessory mineral in metamorphic rocks. A few gems are cut from transparent varieties.

Stibnite Sb_2S_3 (71.4% Antimony)

Color and streak, lead gray. Often tarnishes black. H, 2; G, 4.5. Metallic luster. Slightly sectile. Prominent cleavage. Crystals common, often vertically striated, bent or twisted; also in radial aggregates, bladed, columnar, granular, and compact masses. Sometimes contains gold and silver. Fuses easily in candle flame. Antimony tests. Found in veins with quartz and secondary antimony minerals. Also with galena, barite, cinnabar, sphalerite and gold. The chief source of metallic antimony and its compounds.

Strontianite SrCO_3

Color white, gray, yellow, green. Streak, white. H, 3 to 4; G, 3.7. Vitreous luster. Transparent to translucent. Infusible. Effervesces in hydrochloric acid. Strontium flame color and tests. Crystals needlelike and spear shaped. Found in veins in limestones, marls and occasionally igneous rocks. Sometimes gangue mineral in sulfide veins. Source of strontium.

Sulfur (Brimstone) S

Color various shades of yellow. Streak white to yellow. H, 1.5 to 2.5; G, 1.9 to 2.1. Transparent to translucent. Resinous luster. Crystals are common, also massive, reniform, incrusting, and stalactitic. Fracture conchoidal to uneven. Rather brittle to imperfectly sectile. Easily fusible, burns with bluish flame. When a crystal is held in hand, close to ear, it is heard to crack. Sulfur tests. Found around volcanoes and with gypsum and limestone (reduced from gypsum). Used in sulfuric acid, matches, vulcanizing, medicine, and many other purposes.

Sylvite KCl

Colorless or white, bluish, yellowish, reddish. H, 2; G, 2. Soluble in water. Bitter salty taste. Easily fusible. In granular crystalline masses showing cubic cleavage. Chloride test. Occurs with halite and other evaporites. Source of potassium compounds.

Talc $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$

Color, commonly green, white, or gray; also yellowish, reddish, and brown. Marks cloth. H, 1; G, 2.6 to 2.8. Pearly to greasy luster. Perfect basal cleavage. Layers flexible but not elastic. Compact varieties have uneven fracture. Greasy or soapy feel. Opaque to transparent. Crystals tabular or scaly but indistinctly developed. Occurs as foliated, sometimes radiating, masses, also fibrous or granular. May contain small amounts of nickel. Fuses with great difficulty. Yields water when strongly ignited. Unattacked by acids. Magnesium tests. Occurs as pseudomorph after hornblende, spinel, quartz, dolomite. An alteration product of

magnesium silicates such as augite, hornblende. Commonly found in metamorphic rocks, also with serpentine and magnesite. Occurs frequently as talc schist. Used for plumbing fixtures, electrical switchboards, firebricks, and as crayon. Ground talc used in toilet powders, soaps. Steatite is massive talc. Soapstone is a granular cryptocrystalline variety found in metamorphic rocks.

Tantalite (See Columbite)

Tellurides

Tellurium is one of the few elements that will combine with gold. Gold tellurides include the minerals calaverite, sylvanite, krennerite, and petzite. Tellurides are not very common except in a few mining districts, notably Cripple Creek, Colorado. When decomposed in nitric acid, sponge gold remains. All tellurides give tellurium test.

CALAVERITE - AuTe_2 with small amount of silver. Color and streak yellow to silver white. H, 2.5; G, 9. Brilliant metallic luster. Fuses easily to dark gray globule.

SYLVANITE - $(\text{AuAg})\text{Te}_2$ color and streak same as calaverite, but lighter. H, 1.5 to 2; G, 7.9 to 8.3.

KRENNERITE - $(\text{Au, Ag})\text{Te}_2$ color and streak silver white to brass yellow. H, 2.5; G, 8.3. Ore of gold and silver (at Cripple Creek, Colorado.)

Tetrahedrite (Gray Copper) $(\text{Cu, Fe, Zn, Ag})_{12}\text{Sb}_4\text{S}_{13}$

Color, steel gray to iron black, often with tarnish colors. At times coated with chalcopyrite or sphalerite. Streak black or reddish brown. H, 3 to 4; G, 4.7. Metallic luster, sometimes dull. Uneven fracture. Opaque. Crystals distinctive. Commonly massive-compact, granular, disseminated. Massive tetrahedrite apt to be confused with chalcocite. Composition varies greatly. Copper predominant. Lead, silver, mercury, iron, or zinc may be present. Arsenic may replace antimony. An excess of sulfur is usually observed. Commonly occurs in veins with chalcopyrite, sphalerite, galena, pyrite, quartz, siderite, and barite. An important ore of copper and silver. When arsenic replaces antimony, the mineral is tennantite. When silver predominates, the mineral is freibergite.

Titanite (Sphene) CaTiSiO_5

Color, yellow, green, brown, reddish brown, or black. H, 5 to 5.5; G, 3.5. Resinous to vitreous luster, inclining to adamantine. Well developed cleavage. Conchoidal fracture. Transparent to translucent. Crystal habit varies greatly, often wedge shaped. Occurs also in compact or lamellar masses and in disseminated grains. May also contain some iron. Fuses with slight intumescence on the edges to a dark-colored glass. Only partially decomposed by hydrochloric acid, completely by sulfuric and hydrofluoric acids. Titanium tests. Alters to rutile or ilmenite. Occurs disseminated as an important accessory constituent of many igneous rocks as granite, syenite, and diorite; also in cracks and cavities in metamorphic rocks. Common associates are augite, chlorite, hornblende, zircon, feldspars, and iron minerals. The clear green, yellow, or brownish varieties are used for gems, which are brilliant, have excellent adamantine luster, but are comparatively soft.

Tourmaline, Complex Silicate Of Na, Ca, Al, Fe, Li, Mg, B, F, (OH)

(Not all of these are present in some mineral specimens). Color, usually pitch black or brown; also gray, yellow, green, or red, and more rarely, colorless or white. Often zonal distribution of color, especially in crystals of lighter colors. H, 7 to 7.5; G, 3 to 3.2. Vitreous to resinous luster. Transparent to opaque. Conchoidal to uneven fracture. Commonly in short to long prismatic crystals with vertical striations. Some crystals show a curved triangular cross section. Occurs also in compact and disseminated masses and in radially divergent surbursts; also in loose crystals in unconsolidated deposits. Fusible with difficulty or infusible soluble in acids but gelatinizes after fusion or strong ignition (alone, not with Na_2CO_3). maline is a very characteristic mineral of pegmatite dikes associated with intrusions of granite. It is also rather common in metamorphic rocks, especially metamorphic limestones. Commonly associated with other pegmatite and high temperature minerals, beryl, topaz, fluorite, and others. Stones of good colors are used for gems. Some used as optical crystals.

Tremolite $\text{Ca}_2\text{MgSi}_8\text{O}_{22}(\text{OH})_2$

Color white to light green. H, 5.6 to 6; G, 3 to 3.3. Vitreous to silky luster. Perfect cleavage at angle of 56° (the cleavage angle of amphibole). Prismatic, often in radiating bladed masses. Sometimes silky. Found in impure limestones or schists. Tremolite is the

member of a limited isomorphous series; if more iron is present it is actinolite. A tough compact variety is called nephrite (see jade). Fibrous tremolite is used as asbestos, although its spinning qualities are not so good as crysotile, the serpentine asbestos (see asbestos and serpentine).

Uraninite (See Pitchblende)

Vanadinite $\text{Pb}_5\text{Cl}(\text{VO}_4)_3$

Color, red, yellow, or brown. Streak, white to pale yellow. H, 3; G, 6.7 to 7.2. Resinous luster. Brittle. Uneven to conchoidal fracture. Translucent to opaque. Crystals usually prismatic, sometimes hollow prisms, also compact, fibrous, globular, and in crusts. May contain phosphorus or arsenic. Easily fusible to lead globule with soda on charcoal. Decomposed by hydrochloric acid. Lead and vanadium tests. Occurs associated with lead minerals but never in large quantities. Source of vanadium and its compounds. When arsenic replaces vanadium, the mineral is mimetite.

Wolframite $(\text{Fe}, \text{Mn})\text{WO}_4$

Color, brown to iron black. Streak varies from dark red-brown for manganiferous varieties to black for those containing much iron. H, 5 to 5.5; G, 7 to 7.5. Submetallic to resinous luster. Opaque. Sometimes slightly magnetic. Perfect cleavage in one direction. Uneven fracture. Crystals are thick tabular or short columnar, in bladed or columnar forms. A mixture of MnWO_4 and FeWO_4 in which the composition of one of these constituents is not less than 20 percent and the other not over 80 percent. Wolframite is therefore intermediate between huebnerite, the manganous variety, and ferberite, the iron variety. Occurs as a pseudomorph after scheelite. Iran, manganese, tungsten tests. Fusible to magnetic bead. Occurs in granite pegmatites and as a vein mineral, especially with cassiterite, scheelite. Source of tungsten and its compounds. Used in manufacture of high-speed tool steels and as the filament in electric incandescent lamps.

Wulfenite PbMoO_4

Color yellow, orange, red, gray, white. Streak, white. H, 3; G, 6.8. Vitreous to adamantine luster. Transparent to translucent. Often in square, flat, beveled crystals. Sometimes pyramidal. Crystals sometimes thin. Also occurs in granular masses. Lead and molybdenum tests. Easily fusible, gives lead globule when fused with soda. Found in upper oxidized portions of lead veins. A minor source of molybdenum.

Zeolite Group

The zeolites form a group of hydrous silicates of aluminum, sodium and calcium.

Common zeolites are:

NATROLITE - $\text{Na}_2\text{Al}_2\text{Si}_3\text{O}_{10} \cdot 2\text{H}_2\text{O}$ (slender prismatic crystals)

ANALCIME - $\text{Na}_4\text{AlSi}_2\text{O}_6 \cdot 2\text{H}_2\text{O}$

STILBITE - $(\text{Ca}, \text{Na}_2)\text{Al}_2\text{Si}_6\text{O}_{16} \cdot 6\text{H}_2\text{O}$

CHABAZITE - $\text{CaAl}_2\text{Si}_4\text{O}_{16} \cdot 8\text{H}_2\text{O}$

Generally colorless and transparent or translucent; may be light colored, due to the presence of pigments. H, 3.5 to 5.5; G, 2 to 2.4. Vitreous, silky, pearly luster. Commonly found in good crystals. Most varieties fuse with little difficulty; some with intumescence. All zeolites are readily decomposed by hydrochloric acid and on the evaporation of the acid may gelatinize. Water in closed tube. All are low temperature secondary minerals resulting from decomposition of minerals such as feldspars. Rarely found disseminated; usually lining cavities or in veins in basic igneous rocks, such as basalt, and phonolites; less frequently in granite and mica schist. Calcite is a common associate. Used as water softener.

Zincite (Red Zinc Ore) ZnO

Color, dark red to orange yellow; may have bluish black film. Streak orange yellow. H, 4 to 4.5; G, 5.5. Subadamantine luster. Translucent to opaque. Crystals rare. Perfect basal cleavage. Compact, granular or foliated massive. Usually contains manganese and iron. Zinc tests. Occurs at Franklin Furnace, N.J. with franklinite. With franklinite, rhodanite, willemite, sphalerite, rhodocrosite, calcite. Ore of zinc.

Zircon ZrSiO_4

Color commonly brown or grayish; also red, yellow, blue or colorless. Streak colorless. H, 7.5; G, 4.4 to 4.8. Adamantine luster. Translucent to transparent. Cut zircons possess

good brilliancy and fire. May show luminescence. Insoluble, infusible. Usually in simple well developed crystals; more complex crystals sometimes observed. Also as rounded or angular lumps or grains in sands and gravels. Usually contains a small amount of iron. Occurs disseminated in acid igneous rocks, especially granites and syenites; also found in gneiss, schist, and crystalline limestone. Source of ZrO_2 , which under the name zirkite, is used in ferro-alloys and as a refractory for lining and patching high-temperature furnaces. Also as gems, resembling diamonds but with inferior brilliancy.

COMMERCIAL MATERIALS AND THEIR CHIEF MINERAL SOURCES

Metals

- | | |
|----------|--|
| Aluminum | - Light structural metal.
Bauxite, $Al_2O_3 \cdot 2H_2O$ |
| Antimony | - Principally in non-ferrous alloys.
Stibnite, Sb_2S_3
Jamesonite, $Pb_4FeSb_6S_{14}$ |
| Arsenic | - Poison, alloys, preservative.
Arsenopyrite, $FeAsS$
Enargite, Cu_3AsS_4 (by-product of copper smelting) |
| Bismuth | - Low melting-temperature alloys.
Native bismuth, Bi (by-product)
Bismuthinite, Bi_2S_3 |
| Cadmium | - Low melting-temperature alloys.
Native metal is by-product of zinc smelting
Greenockite, CdS , (not commercial ore) |
| Chromium | - Steel alloy, plating, refractory.
Chromite, $FeCr_2O_4$ |
| Cobalt | - Magnet steel, tool steel.
Cobaltite, $CoAsS$ (by product of nickel industry) |
| Copper | - Rust resisting, ductile metal.
Native copper, Cu
Chalcocite, Cu_2S
Bornite, Cu_5FeS_4
Chalcopyrite, $CuFeS_2$
Tetrahedrite, $(Cu, Fe, Zn, Ag)_{12}Sb_4S_{13}$
Antlerite, $Cu_3(OH)_4SO_4$
Covellite, CuS
Enargite, Cu_3AsS_4 |
| Gold | - Monetary basis, jewelry.
Native gold, Au, with silver
Calaverite, $AuTe_2$ |
| Iron | - Steel; all manner of fabrications.
Hematite, Fe_2O_3
Magnetite, Fe_3O_4
Goethite, $FeO(OH)$ |
| Lead | - Soft, non corrosive metal; pigment.
Galena, PbS
Cerussite, $PbCO_3$
Anglesite, $PbSO_4$ |

- Magnesium - Light weight structural metal, medicine.
Derived from seawater and underground brines.
Carnallite, $\text{KMgCl}_3 \cdot 6\text{H}_2\text{O}$
Magnesite, MgCO_3
- Manganese - Steel Alloy
Pyrolusite, MnO_2
Wad, mixture of oxides
Manganite, MnO(OH)
Psilomelane, $\text{H}_4\text{R}_2\text{Mn}_8\text{O}_{20}$ (R principally Ba)
- Mercury - Amalgamating, electrical, explosives.
Cinnabar, HgS
- Molybdenum - Steel alloy
Molybdenite, MoS_2
- Nickel - Steel alloy, alloys, plating.
Nickeliferous pyrrhotite
Garnierite, $(\text{Ni}, \text{Mg})\text{SiO}_3 \cdot n\text{H}_2\text{O}$
- Platinum - Jewelry, laboratory apparatus, catalyst.
Native platinum, Pt
- Silver - Coins, jewelry.
Native silver, Ag
Argentite, Ag_2S
- Tin - By-product of gold and base metal mines.
Plating, solder, bronze.
Cassiterite, SnO_2
- Titanium - Pigment.
Ilmenite, FeTiO_3
Rutile, TiO_2
- Tungsten - Steel alloy, tungsten carbide.
Scheelite, CaWO_4
Wolframite $(\text{FeMn})\text{W}_2\text{O}_7$
- Vanadium - Steel.
Carnotite, $\text{K}_2\text{O} \cdot 2\text{UO}_3 \cdot \text{V}_2\text{O}_5 \cdot 3\text{H}_2\text{O}$, approximately
Patronite, Peruvian vanadium-containing material of indefinite composition.
- Zinc - Galvanizing, brass.
Sphalerite, ZnS
Smithsonite, ZnCO_3
Hemimorphite, $\text{Zn}_4\text{Si}_2\text{O}_7(\text{OH})_2 \cdot \text{H}_2\text{O}$

Nonmetals

Nonmetals are usually classed according to use.

- Abrasives - Diamond, C
Corundum, Al_2O_3
Quartz, SiO_2
Garnet, silicate of Mg, Al, Fe, Mn, Cr
- Chemical Industry - Sulfur, S
Salt
Halite, NaCl

HANDBOOK FOR THE ALASKAN PROSPECTOR

- Borax
 Borax, $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10 \text{H}_2\text{O}$
 Kernite, $\text{Na}_2\text{B}_4\text{O}_7 \cdot 4 \text{H}_2\text{O}$
- Strontium
 Celestite, SrSO_4
 Strontianite, SrCO_3
- Lithium
 Spodumene, $\text{LiAlSi}_2\text{O}_6$
 Amblygonite, LiAlPO_4
- Fertilizers - Apatite, $\text{Ca}_5(\text{F}, \text{Cl}, \text{OH})(\text{PO}_4)_3$
 Sylvite, KCl
 Chile Saltpeter, NaNO_3
 Limestone, CaCO_3
 Gypsum, $\text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$
- Fluxes - Limestone (Calcite) CaCO_3
 Fluorite, CaF_2
 Quartz, SiO_2
- Gems - Diamond, C
 Corundum, Al_2O_3
 Ruby
 Sapphire
 Beryl, $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$
 Emerald
 Aquamarine
 Morganite
 Garnet, silicate of $\text{Mg}, \text{Al}, \text{Fe}, \text{Mn}, \text{Cr}$
 Zircon, ZrSiO_4
 Topaz, $\text{Al}_2\text{SiO}_4(\text{F}, \text{OH})_2$
 Opal, $\text{SiO}_2 \cdot n \text{H}_2\text{O}$
 Olivine, $(\text{MgFe})_2\text{SiO}_4$
 Peridot
 Quartz, SiO_2
 Rock crystal
 Amethyst
 Heliotrope
 Carnelian
 Onyx
 Chrysoberyl
 Alexandrite
 Tourmaline, Silicate of $\text{Al}, \text{B}, \text{F}, \text{Na}, \text{Ca}, \text{Fe}, \text{Li}, \text{Mg}$
 Rubellite
 Indicolite
 Brazilian emerald
- Optical crystals - Quartz, SiO_2

Calcite, CaCO_3

Fluorite, CaF_2

Tourmaline, silicate of Al, B, F, Na, Ca, Fe, Li, Mg

Ornamental (Semi precious) minerals

Marble, travertine

Calcite, CaCO_3

Jade

Nephrite, $\text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{22}(\text{OH})_2$

Jadeite, $\text{NaAlSi}_2\text{O}_5$

Malachite, $\text{Cu}_2\text{CO}_3 \cdot (\text{OH})_2$

Feldspar

Plagioclase ($\text{NaAlSi}_3\text{O}_8$ - $\text{CaAl}_2\text{Si}_2\text{O}_8$)

Lazulite

Alabaster

Gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$

Agate, SiO_2

Serpentine, $\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$

Pigments

- Limonite

Hematite, Fe_2O_3

Barite, BaSO_4

Plaster, cement

- Calcite, CaCO_3

Gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$

Pottery

- Clay, hydrous silicates of Al, Mg, K, Fe

Feldspar

Orthoclase, KAlSi_3O_8

Microcline, KAlSi_3O_8

Nepheline, $(\text{Na}, \text{K})(\text{Al}, \text{Si})_2\text{O}_4$

Quartz, SiO_2

Refractories

- Magnesite, MgCO_3

Graphite, C

Asbestos

Chrysotile, $\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$

Mica

Muscovite, $\text{KAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2$

Dolomite, $\text{CaMg}(\text{CO}_3)_2$

Sillimanite group

Sillimanite, Al_2SiO_5

Kyanite, Al_2SiO_5

Andalusite, Al_2SiO_5

Dumortierite, $\text{Al}_8\text{BSi}_3\text{O}_{19}(\text{OH})$

DETERMINATIVE MINERALOGY

Every mineral, as already noted, is unique and different from every other mineral. For a few minerals some one outstanding characteristic suffices for identification. Most minerals, however, must be identified by recognizing several qualities, and a few are impossible to isolate without applying chemical and optical tests beyond the scope of this book.

As an aid to rapid identification, most books on mineralogy include tables which are designed to subdivide the minerals into groups, the members of which possess certain characteristics in common. Thus, by determining one property, the person who wishes to identify an unknown mineral is led immediately to a group, thereby eliminating all but a few. A further narrowing of the field is effected by assigning the mineral to a sub-group within the larger group, on the basis of some other property. The final identification is made by observing still other qualities. The process, therefore, is a gradual progression from the general to the particular; groups containing smaller and smaller numbers of minerals are considered, until finally only one choice is left.

As there are several properties of minerals, there are several ways in which determinative tables may be laid out. For example, "Determinative Mineralogy for the Alaskan Prospector" written by Albert S. Wilkerson uses a method based upon the observation of a few physical properties, and then using chemical tests to determine the mineral. The above named book, revised by Leo Mark Anthony in 1961, has been used in the University of Alaska Mining Extension courses for many years and is probably the best of such books for the beginner, especially in Alaska. In this book, more stress is placed upon outstanding physical characteristics. It is probably a good idea for the prospector to look over several tables--all mineralogy books have such tables -- to see the different approaches and possibly to adopt one for his use.

In the following tables, the minerals are first divided into two groups, those with metallic or submetallic luster, and those with nonmetallic luster. Each large group is divided into five subgroups based on color; each color group into two groups based on streak; each streak group into two or three groups based on hardness. All of these groups are shown on a single key page, so it is possible to assign a mineral to a small group by referring to one page only (page 47). Having determined the group, the reader is referred to a particular page and section, where the minerals are listed, together with chemical tests and physical properties which enable an identification to be made.

A study of the descriptions of minerals in this Chapter will indicate that the color and hardness of a mineral may vary. For this reason it is necessary to list the same mineral in several different groups. For the same reason, and because many mineral samples are impure, some specimens will erroneously lead to a group which does not contain the particular mineral. To keep such errors to a minimum, great effort should be made to choose those portions of any particular sample which contain only pure mineral.

Chemical tests play an important part in the use of this determinative table, but such tests are time consuming. The reader is therefore advised to take a little time to look through the list of minerals after the proper page has been located. Following each mineral are some outstanding physical characteristics, and it may often be possible to recognize the mineral without performing the chemical tests. At least the physical properties may so limit the choice that only one or two chemical tests need be made.

As an example of the use of the table consider galena. Galena has a metallic luster, is dark gray, has a black streak, and is 2.5 in hardness. This hardness may place galena in either the "hard" or "soft" category, and further, some galena reflects light in such a way that it may appear light gray. Galena therefore is listed in four places: Sec. 1, Metallic luster, dark gray or black, black streak, soft; Sec. 2, Metallic luster, dark gray or black, black streak, hard; Sec. 7, Metallic luster, metallic white or light metallic gray, black streak, soft; and Sec. 8, Metallic luster, metallic white or light gray, black streak, hard. Upon turning to any one of these sections, a quick reading of the physical properties leads to a suspicion that the mineral is galena because of its perfect cubic cleavage. Reading the description of galena under "Descriptions of Minerals", and a chemical test for lead verifies the suspicion.

One word of warning: It has been proved many times that the possession of a set of determinative tables does not make the owner a mineralogist. The tables are simply a guide for the application of knowledge of physical and chemical properties which can only be learned by study and practice.

Key To Determinative Tables

I. Metallic or submetallic luster

Color	Streak	Hardness	Page	Section
A. Dark gray or black	Black	S	48	1
		H	48	2
		V	48	3
	Not black	S	48	4
		H	49	5
		V	49	6
B. Metallic white or light metallic gray	Black	S	49	7
		H	50	8
		V	50	9
	Not black	S	50	10
		H	50	11
		V	51	12
C. Yellow	Black	H	51	13
		V	51	14
	Not black		51	15
D. Brass, bronze or copper red	Black	H	51	16
		V	51	17
	Not black		51	18
E. Red, brown, blue	Not black		51	19
		S	52	20
		H	52	21
II. Nonmetallic luster	Colored	V	52	22
		S	53	23
		H	53	24
F. Dark gray or black	Uncolored	V	53	24
			53	25
G. Pink, violet, red	Colored	S	53	26
		H	54	27
		V	54	28
H. Green or blue	Uncolored	S	54	29
		H	54	30
		V	55	31
I. Yellow or brown	Colored		55	32
		S	55	33
		H	55	34
J. Colorless, white, light gray	Uncolored	V	56	35
		S	56	36
		H	56	37
	Uncolored	V	57	38
		S	57	39
		H	57	40
	Uncolored	V	58	41
		S	58	42
		H	58	43
	Uncolored	V	59	44

1. METALLIC LUSTER: DARK GRAY OR BLACK: BLACK STREAK: SOFT

Test for sulfur

A. Sulfur present

1. Antimony and lead present: Jamesonite,
- $Pb_4FeSb_6S_{14} \cdot H$
- , 2-3; G, 5.5-6.

Feathery appearance.

2. Lead only present: Galena,
- PbS
- , H, 2.5; G, 7.5. Perfect cubic cleavage.

3. Bismuth present: Bismuthinite,
- Bi_2S_3
- , H, 2; G, 6.7. Resembles stibnite; easily fusible.

4. Silver present: Argentite,
- Ag_2S
- , H, 2-2.5; G, 7.3. Very sectile.

5. Mineral is none of above: Molybdenite,
- MoS_2
- , H, 1-1.5; G, 4.7. Marks paper, bluish tinge, flexible plates. (Verify with molybdenum test).

B. Sulfur absent

1. Manganese present: Pyrolusite,
- MnO_2
- , H, 1-2; G, 4.8. Soils fingers, sooty.

2. Tellurium present: Telluride of silver, gold, or both, H, 1.5-2.5; G, 8-9.

3. None of the above present: Graphite, C, H, 1-2; G, 2.3. Marks paper, black, platy.

2. METALLIC LUSTER: DARK GRAY OR BLACK: BLACK STREAK: HARD

Test for sulfur

A. Sulfur present

1. Test for copper. If copper absent, try test 2 and then 3. If copper present, test for arsenic, antimony, and tin, in order.

- a. Copper and arsenic present: Enargite,
- Cu_3AsS_4
- , H, 3; G, 4.4.

Columnar structure, soils fingers, darker than stibnite.

- b. Copper and antimony present: Tetrahedrite,
- $(Cu, Fe, Zn, Ag)_{12}Sb_4S_{13}$
- , H, 3-4; G, 4.7. Four sided crystals, brittle.

- c. Copper and tin present: Stannite,
- Cu_2FeSnS_4
- , H, 4; G, 4.4. Easily fusible for a tin mineral.

- d. Copper present, arsenic, antimony, tin absent: Chalcocite,
- Cu_2S
- , H, 2.5-3; G, 5.7. Compact, massive, sectile, conchoidal fracture.

2. Copper absent

- a. Antimony and lead present: Jamesonite,
- $Pb_4FeSb_6S_{14}$
- , H, 2-3; G, 5.5-6.

Feathery appearance.

- b. Antimony present, lead absent: Stibnite,
- Sb_2S_3
- , H, 2; G, 4.5. Bladed structure, easily fusible.

- c. Lead present, antimony absent: Galena,
- PbS
- , H, 2-3; G, 7.5. Perfect cubic cleavage.

3. Silver present, lead absent: Argentite,
- Ag_2S
- , H, 2-2.5. G, 7.3.

Very sectile.

B. Sulfur absent

1. Strongly magnetic without any treatment: Magnetite,
- Fe_3O_4
- , H, 6; G, 5.1. Black.

2. Tungsten present: Wolframite,
- $(Fe, Mn)WO_4$
- , H, 5-5.5; G, 7.4. Perfect cleavage one direction, heavy.

3. Manganese present: Pyrolusite,
- MnO_2
- , H, 1-2; G, 4.8. Soils fingers, sooty.

4. Contains Titanium: Ilmenite,
- $FeTiO_3$
- , H, 5-6; G, 4.7. Resembles magnetite, but not so magnetic.

5. Tellurium present: Telluride of gold, silver, or both, H, 1.5-2.5; G, 8-9.

6. Radioactive: Uraninite,
- UO_2
- to
- U_3O_8
- + Pb and rare elements, H, 5.5; G, 9-9.7, in crystalline form.

3. METALLIC LUSTER: DARK GRAY OR BLACK: BLACK STREAK: VERY HARD

1. Strongly magnetic without treatment: Magnetite,
- Fe_3O_4
- , H, 6; G, 5.2.

Black.

2. Tungsten present: Wolframite,
- $(Fe, Mn)WO_4$
- , H, 5-5.5; G, 7-7.5. Perfect cleavage one direction, heavy.

3. Titanium and iron present: Ilmenite,
- $FeTiO_3$
- , H, 5-6; G, 4.7. Resembles magnetite, but not so magnetic.

4. Titanium present, iron absent: Rutile,
- TiO_2
- , H, 6-6.5; G, 4.2. Adamantine luster.

5. Manganese present: Columbite,
- $(Fe, Mn)(Nb, Ta)O_3$
- , H, 6; G, 5.2-7.9. Black, submetallic. Verify with test for Niabium.

4. METALLIC LUSTER: DARK GRAY OR BLACK: NOT A BLACK STREAK: SOFT

Test for sulfur

A. Sulfur present

1. Bismuth present: Bismuthinite,
- Bi_2S_3
- , H, 2; G, 6.7. Resembles stibnite, easily fusible.

2. Antimony and silver present: Pyargyrite,
- Ag_3SbS_3
- , H, 2.5; G, 5.8. Easily

fusible. Ruby red on thin splinters. Indian red streak.

B. Sulfur absent

1. Iron abundantly present: Hematite, Fe_2O_3 . H, 5.5-6.5; G, 5.2. Red brown streak. Hardness less in earthy varieties.

2. Tellurium present: Telluride of gold, silver, or both. H, 1.5-2.5; G, 8-9.

3. If mineral gives poor test or none at all for iron, and does not become magnetic upon heating, it is probably a nonmetallic.

5. METALLIC LUSTER: DARK GRAY OR BLACK: NOT A BLACK STREAK: HARD

Test for sulfur

A. Sulfur present

1. Test for antimony

a. Antimony absent, zinc present: Sphalerite, ZnS with Fe. H, 3.5-4; G, 4. Perfect cleavage, resinous luster. Dark varieties have reddish brown streak.

b. Antimony and copper present: Tetrahedrite, $(\text{Cu}, \text{Fe}, \text{Zn}, \text{Ag})_{12}\text{Sb}_4\text{S}_{13}$. H, 3-4; G, 4.7. Four sided crystals, brittle.

c. Antimony present, copper absent, silver present: Pyargyrite, Ag_3SbS_3 . H, 2.5; G, 5.8. Easily fusible. Ruby red on thin splinters. Indian red streak.

B. Sulfur absent

1. Test for magnetism

a. Powdered mineral magnetic after heating in reducing flame.

1. Water present: Limonite, $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$. H, 5.5 (lower in earthy varieties); G, 3.4-4. Yellow brown streak.

2. Chromium present: Chromite, FeCr_2O_4 . H, 5.5; G, 4.6. Resembles black rock but heavier.

3. Titanium present: Ilmenite, FeTiO_3 . H, 5-6; G, 4.7. Resembles magnetite but not so magnetic.

4. Mineral effervesces: Siderite, FeCO_3 . H, 3.5-4; G, 3.8. Perfect rhombohedral cleavage (like calcite).

5. If none of above, may be: Hematite, Fe_2O_3 . H, 5.5-6.5; G, 5.2. Hardness less in earthy varieties. Red brown streak.

b. Powdered mineral not magnetic after heating in reducing flame.

1. Silver present: Native Silver, Ag. H, 2.5-3; G, 10.5.

Malleable.

2. Tungsten present: Wolframite, $(\text{Fe}, \text{Mn})\text{WO}_4$. H, 5-5.5; G, 7-7.5. Perfect cleavage in one direction, heavy.

3. Tellurium present: Telluride of gold, silver, or both. H, 1.5-2.5; G, 8-9.

4. Mineral radioactive: Uraninite, UO_2 to U_3O_8 + Pb and rare elements. H, 5.5; G, 9-9.7, in crystalline form.

5. Arsenic present: Native Arsenic, As. H, 3.5; G, 5.7. Brittle, breaks in concentric onion-like layers.

6. Manganese present: Manganite, $\text{Mn}_2\text{O}_3 \cdot \text{H}_2\text{O}$. H, 3.5-4; G, 4.3. Striated prismatic crystals.

7. If none of the above, mineral probably is a complex silicate, e.g. augite, hornblende or biotite (check descriptions).

6. METALLIC LUSTER: DARK GRAY OR BLACK: NOT A BLACK STREAK: VERY HARD

Test for iron and for magnetism in powdered mineral after heating in reducing flame.

A. Iron present or mineral magnetic

1. Tungsten present: Wolframite $(\text{Fe}, \text{Mn})\text{WO}_4$. H, 5-5.5; G, 7-7.5. Perfect cleavage in one direction, heavy.

2. Chromium present: Chromite, FeCr_2O_4 . H, 5.5; G, 4.6. Resembles black rock but heavier.

3. Titanium present: Ilmenite, FeTiO_3 . H, 5-6; G, 4.7. Resembles magnetite but not so magnetic.

4. Manganese present: probably Columbite, $(\text{Fe}, \text{Mn})[(\text{Nb}, \text{Ta})\text{O}_3]_2$.

H, 6; G, 5.2-7.9. Black, submetallic. Verify with test for niobium (columbium).

May also be Franklinite, $(\text{Fe}, \text{Mn}, \text{Zn})(\text{FeO}_3)_2$. H, 5.5-6.5; G, 5-5.2. Resembles magnetite but less magnetic. With willemite and zincite. Verify with zinc test.

B. Iron and magnetism absent.

1. Tin present: Cassiterite, SnO_2 . H, 6-7; G, 7. Hard, heavy, light streak.

2. Titanium present: Rutile, TiO_2 . H, 6-6.5; G, 4.2. Adamantine luster.

3. If none of the above, mineral probably is a complex silicate, e.g., garnet, hornblende, or augite. (Look up).

7. METALLIC LUSTER: METALLIC WHITE OR LIGHT METALLIC GRAY: BLACK STREAK:

SOFT

Test for sulfur

A. Sulfur present

1. Antimony present: Stibnite, Sb_2S_3 . H, 2; G, 4.5. Bladed structure, easily fusible.
2. Bismuth present: Bismuthinite, Bi_2S_3 . H, 2; G, 6.7. Resembles stibnite, easily fusible.
3. Antimony and bismuth absent: Molybdenite, MoS_2 . H, 1-1.5; G, 4.7. Marks paper, bluish tinge. (Verify with molybdenum test).
4. Lead present: Galena, PbS . H, 2-3; G, 7.5. Perfect cubic cleavage.
- B. Sulfur absent
 1. Tellurium present: Telluride of gold, silver, or both. H, 1.5-2.5; G, 8-9.
8. METALLIC LUSTER: METALLIC WHITE OR LIGHT METALLIC GRAY: BLACK STREAK: HARD
Test for sulfur.
A. Sulfur present.
 1. Test for copper and tin.
 - a. Copper present, tin absent: Chalcocite, Cu_2S . H, 2.5-3; G, 5.7. Compact, massive, sectile. Conchoidal fracture.
 - b. Copper and tin present: Stannite, $\text{Cu}_2\text{FeSnS}_4$. H, 4; G, 4.4. Easily fusible for a tin mineral.
 2. Test for arsenic.
 - a. Arsenic and cobalt present: Cobaltite, CoAsS . H, 5.5; G, 6-6.4. Perfect cubic cleavage.
 - b. Arsenic and iron present, cobalt absent: Arsenopyrite, FeAsS . H, 5.5-6; G, 6. Silver white.
 - c. Only iron present: Marcasite, FeS_2 . H, 6-6.5; G, 4.9. Cockscomb or arrowhead crystals. Often greenish tarnish.
 3. Lead present: Galena, PbS . H, 2-3; G, 7.5. Perfect cubic cleavage.
 4. Antimony present: Stibnite, Sb_2S_3 . H, 2; G, 4.5. Bladed structure, easily fusible.
- B. Sulfur absent
 1. Cobalt present: Skutterudite, $(\text{Co}, \text{Ni}, \text{Fe})\text{As}_3$. H, 5.5-6; G, 6.5. Brittle. Tin white to silver gray.
 2. Tellurium present: Telluride of gold, silver, or both. H, 1.5-2.5; G, 8-9.
9. METALLIC LUSTER: METALLIC WHITE OR LIGHT METALLIC GRAY: BLACK STREAK: VERY HARD
Test for sulfur
A. Sulfur present
 1. Test for arsenic
 - a. Arsenic and cobalt present: Cobaltite, CoAsS . H, 5.5; G, 6-6.4. Perfect cubic cleavage.
 - b. Arsenic and iron present: Arsenopyrite, FeAsS . H, 5.5-6; G, 6. Silver white.
 - c. Arsenic absent, iron present: Marcasite, FeS_2 . H, 6-6.5; G, 4.9. Cockscomb or arrowhead crystals. Often greenish tarnish.
 - B. Sulfur absent
 1. Cobalt present: Skutterudite, $(\text{Co}, \text{Ni}, \text{Fe})\text{As}_3$. H, 5.5-6; G, 6.5. Brittle. Tin white to silver gray.
 2. Tin present: Cassiterite, SnO_2 . H, 6-7; G, 7. Hard, heavy, light streak.
 3. Titanium present: Rutile, TiO_2 . H, 6-6.5; G, 4.2. Lighter than cassiterite.
10. METALLIC LUSTER: METALLIC WHITE OR LIGHT METALLIC GRAY: NOT A BLACK STREAK: SOFT
Test for bismuth and sulfur
A. Bismuth and sulfur present: Bismuthinite, Bi_2S_3 . H, 2; G, 6.7. Resembles stibnite, easily fusible.
- B. Bismuth present, sulfur absent: Native Bismuth, Bi . H, 2-2.5; G, 9.8. Sectile, heavy, easily fusible.
- C. Bismuth and sulfur absent, tellurium present: Telluride of gold, silver or both. H, 1.5-2.5; G, 8-9.
11. METALLIC LUSTER: METALLIC WHITE OR LIGHT METALLIC GRAY: NOT A BLACK STREAK: HARD
 1. Bismuth present: Native Bismuth, Bi . H, 2-2.5; G, 9.8. Sectile, heavy, easily fusible. Verify by absence of sulfur.
 2. Silver present: Native Silver, Ag . H, 2.5-3; G, 10.5. Malleable.
 3. Tellurium present: Telluride of gold, silver, or both, H, 1.5-2.5; G, 8-9.
 4. Arsenic present: Native Arsenic, As . H, 3.5; G, 5.7. Brittle, breaks in concentric, onion-like layers.
 5. Manganese present: Manganite, $\text{Mn}_2\text{O}_3 \cdot \text{H}_2\text{O}$. H, 3.5-4; G, 4.3. Striated prismatic crystals.

6. If none of the above, test the solubility. If a finely divided portion is insoluble, it is probably Native Platinum, Pt platinum group elements. H, 4.5; G, 15-19. Malleable, ductile.
12. METALLIC LUSTER: METALLIC WHITE OR LIGHT METALLIC GRAY: NOT A BLACK STREAK: VERY HARD
1. Tin present: Cassiterite, SnO_2 . H, 6-7; G, 7. Hard, heavy, light streak.
13. METALLIC LUSTER: YELLOW: BLACK STREAK: HARD
Test for sulfur.
- A. Sulfur present
1. Copper and iron present: Chalcopyrite, CuFeS_2 . H, 3.5-4; G, 4.2. Brass yellow, sometimes with blue tarnish.
2. Iron present, copper absent: Pyrite, FeS_2 . H, 6-6.5; G, 5. Brittle. In cubes, octahedrons, or showing five sided faces. Crystals often striated.
May also be Marcasite, FeS_2 . H, 6-6.5; G, 4.9. Cockscomb or arrowhead crystals. Often greenish tarnish.
- B. Sulfur absent
1. Tellurium present: Telluride of gold, silver, or both. H, 1.5-2.5; G, 8-9.
14. METALLIC LUSTER: YELLOW: BLACK STREAK: VERY HARD
Iron and sulfur present: Pyrite, FeS_2 . H, 6-6.5; G, 5. Brittle. In cubes, octahedrons, or showing five sided faces. Crystals often striated. May also be Marcasite, FeS_2 . H, 6-6.5; G, 4.9. Cockscomb or arrowhead crystals. Often greenish tarnish.
15. METALLIC LUSTER: YELLOW: NOT A BLACK STREAK
1. Iron and water present: Limonite, $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$. H, 5.5 (much softer in earthy varieties); G, 3.4-4. Yellow brown streak.
2. Tellurium present: Telluride of gold, silver, or both. H, 1.5-2.5; G, 8-9.
3. Nickel present: Pentlandite, $(\text{Fe}, \text{Ni})\text{S}$. H, 3.5-4; G, 4.6-5. Occurs with pyrrhotite.
4. If none of above: Gold, Au. H, 2.5-3; G, 15-19. Malleable. Golden yellow in color and streak. Soluble only in aqua regia.
16. METALLIC LUSTER: BRASS, BRONZE, OR COPPER RED: BLACK STREAK: HARD
Test for sulfur.
- A. Sulfur present
1. Copper and iron present: Chalcopyrite, CuFeS_2 . H, 3.5-4; G, 4.2. Brass yellow, sometimes with blue tarnish. May also be Bornite, Cu_5FeS_4 . H, 3; G, 5.1. Purple tarnish, "peacock" colors.
2. Iron present, copper absent: Pyrite, FeS_2 . H, 6-6.5; G, 5. Brittle. In cubes, octahedrons, or showing five sided faces. Crystals often striated. May also be Marcasite, FeS_2 . H, 6-6.5; G, 4.9. Cockscomb or arrowhead crystals. Often greenish tarnish. May also be Pyrrhotite, Fe_{1-x}S . H, 4; G, 4.6. Slightly magnetic. Like dirty brown pyrite.
- B. Sulfur absent
1. Nickel present: Niccolite, Ni As . H, 5-5.5; G, 7.4. Copper red color (verify by arsenic test).
17. METALLIC LUSTER: BRASS, BRONZE, OR COPPER RED: BLACK STREAK: VERY HARD
Test for sulfur.
- A. Sulfur present
1. Iron present: Pyrite, FeS_2 . H, 6-6.5; G, 5. Brittle. In cubes, octahedrons or showing five sided faces. Crystals often striated. May also be Marcasite, FeS_2 . H, 6-6.5; G, 4.9. Cockscomb or arrowhead crystals. Often greenish tarnish.
- B. Sulfur absent
1. Nickel present: Niccolite, Ni As . H, 5-5.5; G, 7.4. Copper red color (verify by arsenic test).
18. METALLIC LUSTER: BRASS, BRONZE, OR COPPER RED: NOT A BLACK STREAK
1. Copper present: Native Copper, Cu. H, 2.5-3; G, 8.9. Malleable, ductile. Copper red on fresh surface.
2. Bismuth present, Native Bismuth, Bi. H, 2-2.5; G, 9.8. Sectile, heavy, easily fusible.
3. Nickel present: Pentlandite, $(\text{Fe Ni})\text{S}$. H, 3.5-4; G, 4.6-5. Occurs with pyrrhotite.
4. If none of above: Gold, Au. H, 2.5-3; G, 15-19. Malleable. Golden yellow in color and streak. Soluble only in aqua regia.
19. METALLIC LUSTER: RED, BROWN, OR BLUE: BLACK STREAK
Test for sulfur
- A. Sulfur present
1. Copper and iron present: Bornite, Cu_5FeS_4 . H, 3; G, 5.1. Purple tarnish, "peacock" colors.
2. Iron present, copper absent: Pyrrhotite, Fe_{1-x}S . H, 4; G, 4.6. Slightly

magnetic. Like dirty brown pyrite.

B. Sulfur absent

1. Nickel present: Niccolite, Ni As . H, 5-5.5; G, 7.4. Copper red color (verify by arsenic test).

2. Tungsten present: Wolframite, $(\text{Fe,Mn})\text{WO}_4$. H, 5-5.5; G, 7-7.5. Perfect cleavage in one direction.

3. Mineral radioactive: Uraninite, UO_2 to U_3O_8 + Pb and rare elements. H, 5.5; G, 9-9.7 in crystalline form.

20. METALLIC LUSTER: RED, BROWN, OR BLUE: NOT A BLACK STREAK: SOFT

A. Sulfur present

1. Mercury present: Cinnabar, HgS . H, 2.5; G, 8. Vermillion to brownish red. Scarlet streak.

2. Silver and antimony present: Pyrargyrite, Ag_3SbS_3 . H, 2.5; G, 5.8. Ruby red on thin splinters. Indian red streak.

3. Silver and arsenic present, antimony absent: Proustite, Ag_3AsS_3 . H, 2-2.5; G, 5.5. Ruby red. Vermillion streak.

4. Copper present: Covellite, CuS . H, 1.5-2; G, 4.6. Indigo blue. Micaceous cleavage giving flexible plates.

B. Sulfur absent

1. Iron and water present: Limonite, $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$. H, 5.5 (much softer in earthy varieties). G, 3.4-4. Yellow brown streak.

2. Iron present, water absent: Hematite, Fe_2O_3 . H, 5.5-6.5; G, 5.2. (Hardness less in earthy varieties). Red brown streak.

21. METALLIC LUSTER: RED, BROWN OR BLUE: NOT A BLACK STREAK: HARD
Test for sulfur, iron, and effervescence.

A. Sulfur present

1. Mercury present: Cinnabar, HgS . H, 2.4; G, 8. Vermillion to brownish red. Scarlet streak.

2. Silver and antimony present: Pyrargyrite, Ag_3SbS_3 . H, 2.5; G, 5.8. Ruby red on thin splinters. Indian red streak.

3. Silver and arsenic present. Proustite, Ag_3AsS_3 . H, 2-2.5; G, 5.5. Ruby red. Vermillion streak.

4. Copper present: Covellite, CuS . H, 1.5-2; G, 4.6. Indigo blue. Micaceous cleavage, giving flexible plates.

5. Zinc present: Sphalerite, ZnS with Fe. H, 3.5-4; G, 4. Perfect cleavage, resinous luster. Dark varieties have reddish brown streak.

B. Iron present

1. Mineral effervesces: Siderite, FeCO_3 . H, 3.5-4; G, 3.8. Perfect rhombohedral cleavage (like calcite).

2. Water present: Limonite, $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$. H, 5.5 (Much softer in earthy varieties); G, 3.4-4. Yellow brown streak.

3. Tungsten present: Wolframite, $(\text{Fe,Mn})\text{WO}_4$. H, 5-5.5; G, 7-7.5. Perfect cleavage one direction.

4. If none of above: Hematite, Fe_2O_3 . H, 5.5-6.5; G, 5.2 (Hardness less in earthy varieties). Red brown streak.

C. Sulfur and iron absent

1. Copper present: Native Copper, Cu . H, 2.5-3; G, 8.9. Malleable, ductile. Copper red on fresh surface. May also be Cuprite, Cu_2O . H, 3.5-4; G, 6. Various shades of red. Red streak.

2. Tungsten present: Wolframite, $(\text{Fe,Mn})\text{WO}_4$. H, 5-5.5; G, 7-7.5. Perfect cleavage one direction.

3. Mineral radioactive: Uraninite, UO_2 to U_3O_8 + Pb and rare elements. H, 5.5; G, 9-9.7 in crystalline form.

22. METALLIC LUSTER: RED, BROWN, OR BLUE: NOT A BLACK STREAK: VERY HARD
Test for iron

A. Iron present

1. Water present: Limonite, $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$. H, 5.5 (much softer in earthy varieties); G, 3.4-4. Yellow brown streak.

2. Tungsten present: Wolframite, $(\text{Fe,Mn})\text{WO}_4$. H, 5-5.5; G, 7-7.5. Perfect cleavage one direction.

3. If none of above: Hematite, Fe_2O_3 . H, 5.5-6.5; G, 5.2 (Hardness less in earthy varieties). Red brown streak.

B. Iron absent

1. Tungsten present: Wolframite $(\text{Fe,Mn})\text{WO}_4$. H, 5-5.5; G, 7-7.5. Perfect cleavage one direction.

2. Titanium present: Rutile, TiO_2 . H, 6-6.5; G, 4.2. Adamantine luster.

3. Tin present (Metallic zinc test): Cassiterite, SnO_2 . H, 6-7; G, 7. Heavy,

light streak.

4. Mineral radioactive: Uraninite, UO_2 to U_3O_8 + Pb and rare elements. H, 5.5; G, 9-9.7 in crystalline form.

23. NONMETALLIC LUSTER: DARK GRAY OR BLACK: COLORED STREAK: SOFT

1. Manganese present: Pyrolusite, MnO_2 . H, 1-2; G, 4.8. Sails fingers, sooty.

2. Mineral has greasy feel and marks paper: Graphite, C. H, 1-2; G, 2.3. Marks paper, black, platy.

May also be Molybdenite, MoS_2 . H, 1-1.5; G, 4.7. Marks paper, bluish tinge. Flexible plates.

24. NONMETALLIC LUSTER: DARK GRAY OR BLACK: COLORED STREAK: HARD OR VERY HARD

A. Iron present

1. Mineral effervesces: Siderite, $FeCO_3$. H, 3.5-4; G, 3.8. Perfect rhombohedral cleavage (like calcite).

2. Water present: Limonite, $Fe_2O_3 \cdot nH_2O$. H, 5.5 (lower in earthy varieties); G, 3.4-4. Yellow brown streak.

3. Tungsten present: Wolframite, $(Fe, Mn)WO_4$. H, 5-5.5; G, 7-7.5. Perfect cleavage one direction, heavy.

4. Chromium present: Chromite, $FeCr_2O_4$. H, 5.5; G, 4.6. Looks like black rock.

5. If none of the above, most likely Hornblende, complex silicate, (look up). H, 5-6; G, 3.2. Perfect prismatic cleavage at 56° and 124° ; or Augite, complex silicate. H, 5-6; G, 3.2. Good prismatic cleavage at 87° and 93° .

B. Iron absent

1. Tungsten present: Wolframite, $(Fe, Mn)WO_4$. H, 5-5.5; G, 7-7.5. Perfect cleavage one direction, heavy.

2. Chromium present: Chromite, $FeCr_2O_4$. H, 5.5; G, 4.6. Resembles black rock, but heavier.

3. Sulfur and zinc present: Sphalerite, ZnS with Fe. H, 3.5-4; G, 4. Perfect cleavage, resinous luster. Dark varieties have reddish brown streak.

4. Mineral is radioactive: Uraninite, UO_2 to U_3O_8 + Pb and rare elements. H, 5.5; G, 9-9.7 in crystalline form.

5. Tin present: Cassiterite, SnO_2 . H, 6-7; G, 7. Light streak, adamantine luster. Often as pebbles.

6. If none of above, most likely Hornblende, complex silicate. H, 5-6; G, 3.2. Perfect prismatic cleavage at 56° and 124° ; or Augite, complex silicate. H, 5-6; G, 3.2. Good prismatic cleavage at 87° and 93° .

25. NONMETALLIC LUSTER: DARK GRAY OR BLACK: UNCOLORED STREAK:

1. Mineral effervesces: Calcite, $CaCO_3$. H, 3; G, 2.7. Perfect rhombohedral cleavage. Large pieces effervesce; or Dolomite, $CaMg(CO_3)_2$. H, 3.5-4; G, 2.9. Curved "saddle shaped" crystals. Powder effervesces.

2. Sulfur and zinc present: Sphalerite, ZnS . H, 3.5-4; G, 4. Perfect cleavage, resinous luster. Dark varieties have reddish brown streak.

3. Titanium present: Titanite, $CaTiSiO_5$. H, 5-5.5; G, 3.5. Wedge shaped crystals.

4. If none of above it is probably one of the following oxides or silicates: Garnet, H, 6.5-7.5; G, 3.5-4.2. Hard. No cleavage; in equidimensional crystals or grains.

Biotite, H, 2.5-3; G, 2.9. Perfect micaceous cleavage.

Augite, H, 5-6; G, 3.2. Good prismatic cleavage at 87° and 93° .

Hornblende, H, 5-6; G, 3.2. Perfect prismatic cleavage at 56° and 124° .

Serpentine, $Mg_3Si_2O_5(OH)_4$. H, 2-5; G, 2.2-2.6. Greasy luster.

Water in closed tube.

Corundum, Al_2O_3 . H, 9; G, 4. Prismatic or barrel shaped crystals.

Very hard.

Staurolite, H, 7-7.5; G, 3.7. Prismatic crystals or cross-shaped twins.

Tourmaline, H, 7-7.5; G, 3-3.2. Prismatic crystals with vertical striations, curved triangular cross sections.

Epidote, H, 6-7; G, 3.3-3.5. Distinctive green color; perfect cleavage one direction.

26. NONMETALLIC LUSTER: PINK, VIOLET, RED: COLORED STREAK: SOFT

Test for sulfur

A. Sulfur present

1. Silver and antimony present: Pyrargyrite, Ag_3SbS_3 . H, 2.5; G, 5.6. Easily fusible. Ruby red in thin splinters. Streak Indian red.

2. Silver and arsenic present: Proustite, Ag_3AsS_3 . H, 2-2.5; G, 5.5.

Ruby red, vermillion streak.

3. Arsenic present, silver absent: Realgar, AsS . H, 1.5-2; G, 3.5.

Bright red to orange. Streak red.

4. Mercury present: Cinnabar, HgS . H, 2.5; G, 8. Vermillion to brownish red. Scarlet streak.

B. Sulfur absent

1. Iron present: Hematite, Fe_2O_3 . H, 6; G, 5.2 (Hardness less in earthy varieties). Red brown streak.

2. Aluminum present: Bauxite, $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$, (approx.). H, 1-3; G, 2-2.5. A dull to earthy rock. Often pisolitic.

27. NONMETALLIC LUSTER: PINK, VIOLET OR RED: COLORED STREAK: HARD
Test for sulfur

A. Sulfur present

1. Silver and antimony present: Pyargyrite, Ag_3SbS_3 . H, 2.5; G, 5.6. Easily fusible. Ruby red in thin splinters. Streak Indian red.

2. Silver and arsenic present: Proustite, Ag_3AsS_3 . H, 2-2.5; G, 5.5. Ruby red, vermillion streak.

3. Mercury present: Cinnabar, HgS . H, 2.5; G, 8. Vermillion to brownish red. Scarlet streak.

4. Arsenic present, silver absent: Realgar, AsS . H, 1.5-2; G, 3.5. Bright red to orange.

5. Calcium present: Anhydrite, CaSO_4 . H, 3-3.5; G, 2.9. Good cleavage 3 directions at right angles.

B. Sulfur absent

1. Tungsten present: Wolframite, $(\text{Fe}, \text{Mn})\text{WO}_4$. H, 5-5.5; G, 7.4. Perfect cleavage one direction, heavy.

2. Iron present, tungsten absent: Hematite, Fe_2O_3 . H, 6; G, 5.2. (Hardness less in earthy varieties). Red brown streak.

3. Copper present: Cuprite, Cu_2O . H, 3.5-4; G, 6.1. Color and streak red.

4. Aluminum present: Bauxite, $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$ (approx.). H, 1-3; G, 2-2.5. Dull to earthy rock. Often pisolitic.

28. NONMETALLIC LUSTER: PINK, VIOLET, OR RED: COLORED STREAK: VERY HARD

1. Tungsten present: Wolframite $(\text{Fe}, \text{Mn})\text{WO}_4$. H, 5-5.5; G, 7.4. Perfect cleavage one direction, heavy.

2. Titanium present: Rutile, TiO_2 . H, 6-6.5; G, 4.2. Adamantine luster.

3. Tin present: Cassiterite, SnO_2 . H, 6-7; G, 7. Light streak.

29. NONMETALLIC LUSTER: PINK, VIOLET, OR RED: UNCOLORED STREAK: SOFT
Test for water and sulfur

1. Water and sulfur present: Gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. H, 2; G, 2.3. Soft.

2. Water and sulfur absent: Sylvite, KCl . H, 2; G, 2. Bitter, salty taste. Cubic cleavage.

30. NONMETALLIC LUSTER: PINK, VIOLET OR RED: UNCOLORED STREAK: HARD
Test for effervescence

A. Mineral effervesces

1. Manganese present: Rhodochrosite, MnCO_3 . H, 3.5-4.5; G, 3.4-3.6. Pink.

2. Manganese absent: Calcite, CaCO_3 . H, 3; G, 2.7. Perfect rhombohedral cleavage. Large fragments effervesce. May also be Dolomite, $\text{CaMg}(\text{CO}_3)_2$. H, 3.5-4; G, 2.9. Saddle shaped crystals. Must be powdered to effervesce.

B. Mineral does not effervesce.

1. Water present on intense heating: Opal, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$. H, 5-6; G, 2. Amorphous. Much water present: Zeolite, group of hydrous silicates. H, 3.5-5.5; G, 2.4. Often in good crystals.

2. Manganese present: Rhodonite, MnSiO_3 . H, 5.5-6; G, 3.4-3.7. Pink color, prismatic cleavage.

3. Strontium present: Celestite, SrSO_4 . H, 3-3.5; G, 4. Good basal cleavage.

4. Fluorine present: Fluorite, CaF_2 . H, 4; G, 3.2. Perfect octahedral cleavage. Cubic crystals.

5. Lead and molybdenum present: Wulfenite, PbMoO_4 . H, 3; G, 6.8. Tabular crystals. Orange to yellow color.

6. Lead and vanadium present: Vanadinite, $\text{Pb}_5\text{Cl}(\text{VO}_4)_3$. H, 3; G, 6.7-7.2. Resinous luster.

7. Contains phosphorus: Monazite, phosphate of rare earths. H, 5-5.5; G, 4.9-5.3. Resinous amber grains. Often in concentrates.

8. Contains barium: Barite, BaSO_4 . H, 3-3.5; G, 4.5. Heavy for nonmetallic. Perfect basal cleavage.
31. NONMETALLIC LUSTER: PINK, VIOLET OR RED: UNCOLORED STREAK: VERY HARD
1. Titanium present: Rutile, TiO_2 . H, 6-6.5; G, 4.2. Adamantine luster.
 2. Tin present (zinc metal test): Cassiterite, SnO_2 . H, 6-7; G, 7. Hard, heavy, light streak.
 3. Manganese present: Rhodonite, MnSiO_3 . H, 5.5-6; G, 3.4-3.7. Pink color, prismatic cleavage.
 4. Phosphorus present: Monazite, phosphate of rare earths. H, 5-5.5; G, 4.9-5.3. Heavy for nonmetallic. Resinous amber grains. In creek concentrates.
 5. Little water on intense heating: Opal, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$. H, 5-6; G, 2. Amorphous.
 6. If none of the above, it is probably one of the following:
 - Quartz, SiO_2 . H, 7; G, 2.6. Glassy luster, conchoidal fracture.
 - Feldspar, group of aluminum silicates. H, 6; G, 2.6-2.8. Good cleavage two directions. See descriptions.
 - Garnet, group of silicates. H, 6.5-7.5; G, 3.5-4.2. Usually in well formed, equidimensional crystals.
 - Spodumene, $\text{LiAl}(\text{SiO}_3)_2$. H, 6.5-7; G, 3.2. Perfect prismatic cleavage at 87° and 93° . Lithium test.
 - Corundum, Al_2O_3 . H, 9; G, 4. Very hard. Rhombohedral parting or in prismatic or barrel shaped crystals.
 - Beryl, $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$. H, 7.5-8; G, 2.8. Six sided prismatic crystals.
 - Tourmaline, complex silicate. H, 7-7.5; G, 3-3.2. Prismatic crystals with vertical striations. Curved triangular cross sections.
 - Zircon, ZrSiO_4 . H, 7.5; G, 4.4-4.8. Pointed prismatic crystals.
32. NONMETALLIC LUSTER: GREEN OR BLUE: COLORED STREAK
- Test for copper
- A. Copper present
1. Mineral effervesces: Azurite, $2\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$. H, 3.5-4; G, 3.8. Blue; or Malachite, $\text{Cu}_2\text{CO}_3 \cdot (\text{OH})_2$. H, 3.5-4; G, 4. Green.
 2. Does not effervesce: Chrysocolla, $\text{CuSiO}_3 \cdot 2\text{H}_2\text{O}$. H, 2-4; G, 2-2.2. Blue green. Enamel-like appearance.
- B. Copper absent.
1. Augite, complex silicate. H, 5-6; G, 3.2. Good prismatic cleavage at 87° and 93° .
 2. Hornblende, complex silicate. H, 5-6; G, 3.2. Perfect prismatic cleavage at 56° and 124° .
 3. Chlorite, complex hydrous silicate. H, 1-2.5; G, 2.6-3. Mica like cleavage. Green flexible scales. Yields water.
33. NONMETALLIC LUSTER: GREEN OR BLUE: UNCOLORED STREAK: SOFT
1. Copper present: Chrysocolla, $\text{CuSiO}_3 \cdot 2\text{H}_2\text{O}$. H, 2-4; G, 2-2.2. Blue-green. Enamel-like appearance.
 2. Titanium present: Titanite, CaTiSiO_5 . H, 5-5.5; G, 3.5. Wedge shaped crystals.
 3. Biotite, complex hydrous silicate. H, 2.5-3; G, 2.9. Black, green. Perfect micaceous cleavage.
 4. Chlorite, complex hydrous silicate. H, 1-2.5; G, 2.6-3. Mica like cleavage. Green flexible scales. Yields water.
 5. Asbestos, a group of amphibole or serpentine minerals. H, 2-6; G, 2-3.3. Distinctive asbestos fibers.
 6. Serpentine, $\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$. H, 2-5; G, 2.2-2.6. Green color. Greasy luster.
 7. Sylvite, KCl. H, 2; G, 2. Bitter salty taste.
34. NONMETALLIC LUSTER: GREEN OR BLUE: UNCOLORED STREAK: HARD
1. Mineral effervesces and zinc present: Smithsonite, ZnCO_3 . H, 4.5-5; G, 4.4. Heavy for nonmetallic, hard for carbonate.
 2. Mineral effervesces and strontium present: Strontianite, SrCO_3 . H, 3-4; G, 3.7. Crystals needlelike and spear shaped. Heavy for nonmetallic.
 3. Mineral effervesces: Calcite, CaCO_3 . H, 3; G, 2.7. Perfect rhombohedral cleavage. Large fragments effervesce. May also be Dolomite, $\text{CaMg}(\text{CO}_3)_2$. H, 3.5-4; G, 2.9. Saddle shaped crystals. Must be powdered to effervesce.
 4. Zinc present, mineral does not effervesce: Hemimorphite, $\text{Zn}_4\text{Si}_2\text{O}_7(\text{OH}) \cdot 2\text{H}_2\text{O}$. H, 4.5-5; G, 3.5. Yields water.
 5. Strontium present, mineral does not effervesce: Celestite, SrSO_4 .

H, 3-3.5; G, 4. Good basal cleavage.

6. Copper present: Chrysocolla, $\text{CuSiO}_3 \cdot 2\text{H}_2\text{O}$. H, 2-4; G, 2-2.2. Blue green. Enamel like appearance.

7. Titanium present: Titanite, CaTiSiO_5 . H, 5-5.5; G, 3.5. Wedge shaped crystals.

8. Sulfur and barium present: Barite, BaSO_4 . H, 3-3.5; G, 4.5. Heavy for nonmetallic. Perfect basal cleavage.

9. Phosphorus present: Apatite, $\text{Ca}_5(\text{F}, \text{Cl}, \text{OH})(\text{PO}_4)_3$. H, 5; G, 3.2. Prismatic or tabular crystals. Vitreous to sub-resinous luster.

10. If none of above, it is probably one of the following:

Biotite, complex hydrous silicate. H, 2.5-3; G, 2.9. Perfect micaceous cleavage.

Opal, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$. H, 5-6; G, 2. Amorphous. Yields water on intense heating.

Fluorite, CaF_2 . H, 4; G, 3.2. Perfect octahedral cleavage. Cubic crystals.

Augite, complex silicate. H, 5-6; G, 3.2. Good prismatic cleavage at 87° and 93° .

Hornblende, complex silicate. H, 5-6; G, 3.2. Perfect prismatic cleavage at 56° and 124° .

Serpentine, $\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$. H, 2-5; G, 2.2-2.6. Green color, greasy luster.

Sodalite, $\text{Na}_4\text{Al}_3\text{Si}_3\text{O}_{12}\text{Cl}$. H, 5.5-6; G, 2.2. Usually blue.

35. NONMETALLIC LUSTER: GREEN OR BLUE: UNCOLORED STREAK: VERY HARD

1. Olivine, $(\text{Mg}, \text{Fe})_2\text{SiO}_4$. H, 6.5-7; G, 3.3-3.6. Sugary granular structure.

2. Beryl, $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$. H, 7.5-8; G, 2.8. Six-sided prismatic crystals.

3. Epidote, $\text{Ca}_2(\text{Al}, \text{Fe})_3(\text{SiO}_4)_3(\text{OH})$. H, 6-7; G, 3.3-3.5. Pistachio green. Perfect cleavage one direction.

4. Opal, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$. H, 5-6; G, 2. Amorphous. Yields a little water on intense heating.

5. Tourmaline, complex silicate. H, 7-7.5; G, 3-3.2. Prismatic crystals with vertical striations. Curved triangular cross sections.

6. Zircon, ZrSiO_4 . H, 7.5; G, 4.4-4.8. Painted prismatic crystals.

7. Spadumene, $\text{LiAl}(\text{SiO}_3)_2$. H, 6.5-7; G, 3.2. Perfect prismatic cleavage at 87° and 93° . Lithium test.

8. Sadalite, $\text{Na}_4\text{Al}_3\text{Si}_3\text{O}_{12}\text{Cl}$. H, 5.5-6; G, 2.2. Usually blue.

36. NONMETALLIC LUSTER: YELLOW OR BROWN: COLORED STREAK: SOFT

Test for sulfur

A. Sulfur present

1. Arsenic present: Orpiment, As_2S_3 . H, 1.5-2; G, 3.5. Yellow. Flexible scales.

2. Arsenic absent: Native sulfur, S. H, 1.5-2.5; G, 2. Burns with blue flame.

B. Sulfur absent

1. Iron and water present: Limonite, $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$. H, 5.5 (Lower in earthy varieties); G, 3.4-4. Yellow brown streak.

2. Antimony present: Cervantite, $\text{Sb}_2\text{O}_3 \cdot \text{Sb}_2\text{O}_5$. H, 4-5; G, 4. (Appears softer in earthy varieties). As yellow coating on other antimony minerals).

3. Mineral radioactive: Carnotite, $\text{K}_2\text{O} \cdot 2\text{UO}_3 \cdot \text{V}_2\text{O}_5 \cdot 3\text{H}_2\text{O}$. As coating or impregnation.

4. Aluminum present: Bauxite, $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$, (approx.). H, 1-3; G, 2-2.5. Dull to earthy rock. Sometimes pisolitic.

37. NONMETALLIC LUSTER: YELLOW OR BROWN: COLORED STREAK: HARD

A. Iron present

1. Iron and water present: Limonite, $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$. H, 5.5 (Lower in earthy varieties); G, 3.4-4. Yellow brown streak.

2. Iron present, mineral effervesces; Siderite, FeCO_3 . H, 3.5-4; G, 3.8. Perfect rhombohedral cleavage (like calcite).

3. Iron present, water absent, does not effervesce: Hematite, Fe_2O_3 . H, 6; G, 5.2. (Hardness less in earthy varieties). Red brown streak.

4. Iron and tungsten present: Wolframite, $(\text{Fe}, \text{Mn})\text{WO}_4$. H, 5-5.5; G, 7-7.5. Perfect cleavage one direction, heavy.

B. Test for sulfur

1. Sulfur and zinc present: Sphalerite, ZnS . H, 3.5-4; G, 4. Perfect cleavage, resinous luster. Dark varieties have reddish brown streak.

2. Sulfur only present: Native sulfur, S. H, 1.5-2.5; G, 2. Burns with

blue flame

C. Neither iron nor sulfur present.

1. Zinc present, sulfur absent: Zincite, ZnO . H, 4-4.5; G, 5.5. Red color, orange yellow streak. With franklinite.

2. Antimony present: Cervantite, $\text{Sb}_2\text{O}_3 \cdot \text{Sb}_2\text{O}_5$. H, 4.5; G, 4. (Appears softer in earthy varieties). As yellow coating on other antimony minerals.

3. Aluminum present: Bauxite, $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$ (approx.). H, 1-3; G, 2-2.5. Dull to earthy rock. Often pisolitic.

38. NONMETALLIC LUSTER: YELLOW OR BROWN: COLORED STREAK: VERY HARD

1. Tungsten present: Wolframite, $(\text{Fe}, \text{Mn})\text{WO}_4$. H, 5-5.5; G, 7-7.5

Perfect cleavage one direction, heavy.

2. Titanium present: Rutile, TiO_2 . H, 6-6.5; G, 4.2. Adamantine luster.

3. Tin present (zinc metal test): Cassiterite, SnO_2 . H, 6-7; G, 7.

Hard, heavy, light streak.

39. NONMETALLIC LUSTER: YELLOW OR BROWN: UNCOLORED STREAK: SOFT

1. Sulfur and water present: Gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. H, 2; G, 2.3. Soft.

2. Sulfur only present: Native Sulfur, S. H, 1.5-2.5; G, 2. Burns with blue flame.

3. Antimony present: Cervantite, $\text{Sb}_2\text{O}_3 \cdot \text{Sb}_2\text{O}_5$. H, 4.5; G, 4 (Appears softer in earthy varieties). As yellow coating on other antimony minerals.

4. If none of the above, it may be one of the following:

Muscovite, white mica, complex hydrous silicate. H, 2-3; G, 2.8-3.1. Perfect micaceous cleavage.

Talc, $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$. H, 1; G, 2.6-2.8. Very soft, marks cloth.

Asbestos, complex silicates. H, 2-6; G, 2.2-2.3. Distinctive asbestos fibers. Infusible.

Kaolinite, $\text{H}_4\text{Al}_2\text{Si}_2\text{O}_9$. H, 2-2.5; G, 2.6. Earthy odor when breathed upon. Adheres to tongue.

Sylvite, KCl. H, 2; G, 2. Bitter salty taste. Cubic cleavage.

40. NONMETALLIC LUSTER: YELLOW OR BROWN: UNCOLORED STREAK: HARD

A. Sulfur present

1. Barium present: Barite, BaSO_4 . H, 3-3.5; G, 4.5. Heavy for nonmetallic. Perfect basal cleavage.

2. Zinc present: Sphalerite, ZnS . H, 3.5-4; G, 4. Perfect cleavage. Resinous luster. Dark varieties have reddish brown streak.

3. Native Sulfur, S. H, 1.5-2.5; G, 2. Burns with blue flame.

B. Mineral effervesces.

1. Iron present: Siderite, FeCO_3 . H, 3.5-4; G, 3.7-3.9. Perfect rhombohedral cleavage (like calcite).

2. Lead present: Cerussite, PbCO_3 . H, 3-3.5; G, 6.4-6.6. Adamantine luster. Heavy for nonmetallic.

3. Zinc present: Smithsonite, ZnCO_3 . H, 4.5-5; G, 4.3-4.5. Hard for carbonate. Heavy for nonmetallic. Colloform.

4. Strontium present: Strontianite, SrCO_3 . H, 3-4; G, 3.7. Crystals needlelike and spear shaped. Heavy for nonmetallic.

5. None of above: Calcite, CaCO_3 . H, 3; G, 2.7. Perfect rhombohedral cleavage. Large fragments effervesce. May also be Dolomite, $\text{CaMg}(\text{CO}_3)_2$. H, 3.5-4; G, 2.9. Saddle shaped crystals. Must be powdered to effervesce.

C. Does not contain sulfur nor effervesce.

1. Tungsten present: Scheelite, CaWO_4 . H, 4.5-5; G, 5.9-6. Heavy for nonmetallic. Fluorescent in ultraviolet light.

2. Antimony present: Cervantite, $\text{Sb}_2\text{O}_3 \cdot \text{Sb}_2\text{O}_5$. H, 4-5; G, 4. (Appears softer in earthy varieties). As yellow coating on other antimony minerals.

3. Zinc present: Hemimorphite, $\text{Zn}_4\text{Si}_2\text{O}_7(\text{OH})_2 \cdot \text{H}_2\text{O}$. H, 4.5-5; G, 3.4. Yields water.

4. Lead and molybdenum present: Wulfenite, PbMoO_4 . H, 3; G, 6.8. Tabular crystals. Orange to yellow color.

5. Lead and vanadium present: Vanadinite. $\text{Pb}_5\text{Cl}(\text{VO}_4)_3$. H, 3; G, 6.7-7.2. Resinous luster.

6. Manganese present: Rhodonite, MnSiO_3 . H, 5.5-6; G, 3.4. Usually pink color. Prismatic cleavage.

7. Phosphorus present: Apatite, $\text{Ca}_5(\text{F}, \text{Cl}, \text{OH})(\text{PO}_4)_3$. H, 5; G, 3.2. Prismatic or tabular crystals. Vitreous to subresinous luster. May also be Monazite, phosphate of rare earths. H, 5-5.5; G, 4.9-5.3. Heavy for nonmetallic. Resinous amber grains. In creek concentrates.

8. Titanium present: Titanite, CaTiSiO_5 . H, 5-5.5; G, 3.5. Wedge shaped crystals.

9. If none of the above, it may be one of the following:

Muscovite, white mica, complex hydrous silicate. H, 2-3; G, 2.8-3.1. Perfect micaceous cleavage.

Asbestos, complex silicates. H, 2-6; G, 2.2-2.3. Distinctive asbestos fibers. Infusible.

Fluorite, CaF_2 . H, 4; G, 3.2. Perfect octahedral cleavage. Cubic crystals.

Zeolite, group of hydrous silicates. H, 3.5-5; G, 2-2.4. Yields water. Often in good crystals.

Opal, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$. H, 5-6; G, 2. Amorphous. Yields a little water on intense heating.

Kaolinite, $\text{H}_4\text{Al}_2\text{Si}_2\text{O}_9$. H, 2-2.5; G, 2.6. Earthy odor when breathed upon. Adheres to tongue. Aluminum present.

Nepheline, $(\text{Na}, \text{K})(\text{Al}, \text{Si})_2\text{O}_4$. H, 5.5-6; G, 2.6. Greasy luster. In certain igneous rocks. Aluminum present.

41. NONMETALLIC LUSTER: YELLOW OR BROWN: UNCOLORED STREAK: VERY HARD

1. Tin present (Zinc metal test): Cassiterite, SnO_2 . H, 6-7; G, 7. Light streak. Adamantine luster. Often as pebbles.

2. Manganese present: Rhodonite, MnSiO_3 . H, 5.5-6; G, 3.4. Usually pink color. Prismatic cleavage.

3. Phosphorus present: Monazite, phosphate of rare earths. H, 5-5.5; G, 4.9-5.3. Heavy for nonmetallic. Resinous amber grains. In creek concentrates.

4. Titanium present: Titanite, CaTiSiO_5 . H, 5-5.5; G, 3.5. Wedge shaped crystals.

5. Aluminum present: Feldspar, group of aluminum silicates. H, 6; G, 2.6-2.8. Good cleavage two directions; or Sillimanite group, Al_2SiO_5 . H, 6-7; G, 3.2-3.3. Prismatic or bladed. See descriptions of members of group; or Nepheline,

$(\text{Na}, \text{K})(\text{Al}, \text{Si})_2\text{O}_4$. H, 5.5-6; G, 2.6. Greasy luster. In certain igneous rocks.

6. Lithium present: Spodumene, $\text{LiAl}(\text{SiO}_3)_2$. H, 6.5-7; G, 3.2. Perfect prismatic cleavage at 87° and 93° .

7. Yields water: Epidote, $\text{Ca}_2(\text{Al}, \text{Fe})_3(\text{SiO}_4)_3(\text{OH})$. H, 6-7; G, 3.3-3.5. Usually green. Perfect cleavage one direction. Little water.

8. If none of above, may be one of following:

Quartz, SiO_2 . H, 7; G, 2.6. Glassy luster, conchoidal fracture.

Chalcedony, SiO_2 . H, 7; G, 2.6. Amorphous, waxy, variety of quartz.

Garnet, group of silicates. H, 6.5-7.5; G, 3.5-4.2. Usually in well formed, equidimensional crystals.

Tourmaline, complex silicate. H, 7-7.5; G, 3-3.2. Prismatic crystals with vertical striations. Curved triangular cross sections.

Corundum, Al_2O_3 . H, 9; G, 4. Very hard. Prismatic or barrel shaped crystals.

Beryl, $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$. H, 7.5-8; G, 2.8. Six sided prismatic crystals.

Zircon, ZrSiO_4 . H, 7.5; G, 4.4-4.8. Pointed prismatic crystals.

Opal, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$. H, 5-6; G, 2. Amorphous. Yields a little water on intense heating.

42. NONMETALLIC LUSTER: COLORLESS, WHITE, OR LIGHT GRAY: UNCOLORED STREAK SOFT

1. Sulfur and water present: Gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. H, 2; G, 2.3. Soft.

2. Silver present: Cerargyrite, AgCl . H, 2-3; G, 5.5. Hornlike appearance.

3. Aluminum present: Bauxite, $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$, (approx.). H, 1-3; G, 2-2.5. A dull to earthy rock. Often pisotitic; or Kaolinite, $\text{H}_4\text{Al}_2\text{Si}_2\text{O}_9$. H, 2-2.5; G, 2.6.

Earthy odor when breathed upon; adheres to tongue; or Muscovite, complex hydrous silicate. H, 2-3; G, 2.8-3.1. Perfect micaceous cleavage.

4. If none of above, may be one of following:

Muscovite, complex hydrous silicate. H, 2-3; G, 2.8-3.1. Perfect micaceous cleavage. See 3 above.

Talc, $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$. H, 1; G, 2.6-2.8. Very soft, marks cloth.

Asbestos, complex silicates. H, 2-6; G, 2.2-2.3. Distinctive asbestos fibers. Infusible.

Cryolite, Na_3AlF_6 . H, 2.5; G, 3. Paraffin-like appearance.

Sylvite, KCl . H, 2; G, 2. Bitter salty taste. Cubic cleavage.

Diatomaceous earth (form of Opal) $\text{SiO}_2 \cdot n\text{H}_2\text{O}$. Appears softer than opal. Resembles chalk.

43. NONMETALLIC LUSTER: COLORLESS, WHITE, OR LIGHT GRAY: UNCOLORED STREAK: HARD

A Sulfur present:

1. Barium present: Barite, BaSO_4 . H, 3-3.5; G, 4.5. Heavy for nonmetallic.

Perfect basal cleavage.

2. Lead present: Anglesite, PbSO_4 . H, 3; G, 6.2-6.4. Heavy for non-metallic. Adamantine luster.

3. Calcium present: Anhydrite, CaSO_4 . H, 3-3.5; G, 2.9. Good cleavage three directions at right angles.

4. Strontium present: Celestite, SrSO_4 . H, 3-3.5; G, 4. Good basal cleavage.

B. Mineral effervesces

1. Lead present: Cerussite, PbCO_3 . H, 3-3.5; G, 6.4-6.6. Adamantine luster. Heavy for nonmetallic.

2. Zinc present: Smithsonite, ZnCO_3 . H, 4.5-5; G, 4.3-4.5. Hard for carbonate. Heavy for nonmetallic. Colloform.

3. Strontium present: Strontionite, SrCO_3 . H, 3-4; G, 6.5. Crystals needlelike and spear shaped. Heavy for nonmetallic.

4. If none of above, it is Calcite, CaCO_3 . H, 3; G, 2.7. Perfect rhombohedral cleavage. Large fragments effervesce; or Dolomite, $\text{CaMg}(\text{CO}_3)_2$. H, 3.5-4; G, 2.9. Saddle shaped crystals. Must be powdered to effervesce; or

Magnesite, MgCO_3 . H, 3.5-5; G, 3.2. Often compact, no cleavage. Effervesces in hot hydrochloric acid.

C. Does not contain sulfur nor effervesce.

1. Tungsten present: Scheelite, CaWO_4 . H, 4.5-5; G, 5.9-6. Heavy for nonmetallic. Fluorescent in ultra-violet light.

2. Zinc present: Hemimorphite, $\text{Zn}_4\text{Si}_2\text{O}_7(\text{OH})_2 \cdot \text{H}_2\text{O}$. H, 4.5-5; G, 3.4. Yields water.

3. Silver present: Cerargyrite, AgCl . H, 2-3; G, 5.5. Hornlike appearance.

4. Aluminum present: Bauxite, $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$, (approx.). H, 1-3; G, 2-2.5. A dull to earthy rock. Often pisolitic.

Muscovite, complex hydrous silicate. H, 2-3; G, 2.8-3.1. Perfect micaceous cleavage.

Leucite, $\text{KAl}(\text{SiO}_3)_2$. H, 5.5-6; G, 2.5. In igneous rocks. In 24-sided crystals.

Nepheline, $(\text{Na}, \text{K}) (\text{Al}, \text{Si})_2\text{O}_4$. H, 5.5-6; G, 2.6. Greasy luster. In certain igneous rocks.

Sodalite, $\text{Na}_2\text{Al}_3\text{O}_{12}\text{Cl}$. H, 5.5-6; G, 2.1-2.3. In certain igneous rocks. Usually blue.

5. Phosphorus present: Apatite, $\text{Ca}_5(\text{F}, \text{Cl}, \text{OH})(\text{PO}_4)_3$. H, 5; G, 3.2. Prismatic or tabular crystals. Vitreous to subresinous luster.

6. Lead and molybdenum present: Wulfenite, PbMoO_4 . H, 3; G, 6.8. Tabular crystals. Orange to yellow color.

7. Titanium present: Titanite, CaTiSiO_5 . H, 5-5.5; G, 3.5. Wedge shaped crystals.

8. Yields water: Zeolite, group of hydrous silicates. H, 3.5-5; G, 2-2.4. Abundant water. Often in good crystals.

Opal, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$. H, 5-6; G, 2. Amorphous. Yields a little water on intense heating.

Hemimorphite. See 2 above.

9. If none of the above, it may be:

Fluorite, CaF_2 . H, 4; G, 3.2. Perfect octahedral cleavage. Cubic crystals; or

Cryolite, Na_3AlF_6 . H, 2.5; G, 3. Paraffin-like appearance.

44. NONMETALLIC LUSTER: COLORLESS, WHITE, OR LIGHT GRAY: UNCOLORED STREAK: VERY HARD

1. Aluminum present: Feldspar, group of aluminum silicates. H, 6; G, 2.6-2.8. Good cleavage two directions. See descriptions.

Spodumene, $\text{LiAl}(\text{SiO}_3)_2$. H, 6.5-7.5; G, 3.2. Perfect prismatic cleavage at 87° and 93° . Lithium test.

Corundum, Al_2O_3 . H, 9; G, 4. Very hard. Rhombohedral parting or in prismatic or borrel shaped crystals.

Leucite, $\text{KAl}(\text{SiO}_3)_2$. H, 5.5-6; G, 2.5. In igneous rocks. In 24-sided crystals.

Nepheline, $(\text{Na}, \text{K})(\text{Al}, \text{Si})_2\text{O}_4$. H, 5.5-6; G, 2.6. Greasy luster in certain igneous rocks.

Sodalite, $\text{Na}_4\text{Al}_3\text{Si}_3\text{O}_{12}\text{Cl}$. H, 5.5-6; G, 2.1-2.3. In certain igneous rocks. Usually blue.

Sillimanite group, Al_2SiO_5 . H, 6-7; G, 3.2-3.3. Prismatic or bladed. See descriptions of members of group.

2. Titanium present: Titanite, CaTiSiO_5 . H, 5-5.5; G, 3.5. Wedge shaped crystals.

3. Water present: Opal, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$. H, 5-6; G, 2. Yields a little water on intense heating.
4. If none of above, it is probably one of the following:
 - Quartz, SiO_2 . H, 7; G, 2.6. Glassy luster. Conchoidal fracture.
 - Chalcedony, SiO_2 . H, 7; G, 2.6. Amorphous, waxy, variety of quartz.
 - Corundum, Al_2O_3 . See 1 above.
 - Beryl, $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$. H, 7.5-8; G, 2.8. Six sided prismatic crystals. Usually green.
 - Tourmaline, complex silicate. H, 7-7.5; G, 3-3.2. Prismatic crystals with vertical striations. Curved triangular cross sections.
 - Zircon, ZrSiO_4 . H, 7.5; G, 4.4-4.8. Pointed prismatic crystals.

References

- Berry, I. G., and Mason, Brian, 1959, *Mineralogy*: W. H. Freeman and Co., San Francisco
- Ford, W. E., 1932, *Dana's Textbook of Mineralogy*: John Wiley and Sons, Inc., New York
- Hurlbut, Cornelius S., Jr., 1961, *Dana's Manual of Mineralogy*, Seventeenth Ed: John Wiley and Sons, Inc., New York
- Lewis, J. V., Hawkins, A. C., 1931, *Determinative Mineralogy*: John Wiley and Sons, Inc., New York
- Smith, Orsino C., 1952, *Identification and Qualitative Chemical Analysis of Minerals*, Second Ed.: D. Van Nostrand and Company, Inc., New York
- Wilkerson, Albert S., 1961, *Determinative Mineralogy for the Alaskan Prospector*: University of Alaska

Chapter 3

THE STUDY OF ROCKS

INTRODUCTION

Rocks are any naturally occurring masses of material that make up an appreciable portion of the earth's crust. Usually they are a mixture of minerals. They may be hard or soft, or be composed of crystalline or amorphous minerals. Some rocks consist of one mineral only; most rocks are made up of more than one. When only the physical descriptions and classifications of rocks are considered, the study is called petrography. The consideration of the origin of rock is called petrogenesis. The study of all aspects of rocks is called petrology. Petrology embraces the broad fields of occurrence and association as well as petrography and petrogenesis.

Rocks are classified as igneous, metamorphic, or sedimentary.

IGNEOUS ROCKS

All igneous rocks were once magma, a hot solution of liquids and gases which, when cooled and hardened, formed igneous rocks. Magmas are formed deep within the earth; they may remain there and eventually cool, or they may be forced near to or onto the surface of the earth. As the magma cools, minerals are formed. Different minerals form at different temperatures, hence the minerals formed toward the end of the cooling period are different from those formed at the beginning. When magmas form deep within the earth, they cool slowly, and the minerals have time to form into large crystals. These minerals form intrusive igneous rocks.

Magmas which pour out onto the surface of the earth cool rapidly and the crystals formed are much smaller than those in intrusive rocks. Such magma poured out on the surface of the earth is called lava; if it is expelled by gas with explosive force it forms pyroclastic deposits. Together these form extrusive igneous rocks.

Intrusive Igneous Rock Forms

Intrusive rock masses occur in various shapes, of which a few of the most common forms are as follows: (See Fig. 3-1).

BATHOLITHS - The largest igneous rock masses are batholiths, irregularly shaped masses exceeding 40 square miles in area and having no known floor. They increase in size with depth. Batholiths are formed deep within the earth, but through the process of erosion may eventually be partly exposed at the surface of the earth. The cores of many mountain ranges are batholiths.

Examples of batholiths: The Sierra Nevada batholith in California is 400 miles long and 80 miles wide.

A batholith in Idaho covers 16,000 square miles.

The batholith of the Canadian Coast Range is 1100 miles long and has an area of about 100,000 square miles.

STOCKS - Stocks are irregular masses differing from batholiths in that they are less than 40 square miles in area. They often have circular shaped surface outcrops.

SILLS - Sills are formed when magma is forced between layers of sedimentary rocks or foliated metamorphic rocks. Sills form tabular sheets of rock lying parallel to the layers of country rock. They vary greatly in size.

Examples of sills: A sill at Mount Royal in Montreal is 2 inches to 4 inches thick and 6 feet wide.

A sill in Glacier National Park, Montana is 100 feet thick and covers 2,000 square miles.

DIKES - Sheetlike magmatic intrusions that cut across rock strata or igneous masses are called dikes. Dikes also vary greatly in size and tend to be inclined or vertical rather than horizontal. Dikes may be a few yards to 100 miles in length and several inches to 500 feet in thickness.

LACCOLITHS - Laccoliths are dome shaped masses of igneous rock which, like sills, lie within the bedding planes of the intruded rocks. The bottom of the laccolith is often nearly flat. The laccolith may dome up in the overlying layered rocks.

NECKS OR PLUGS - Necks or plugs are columns of hardened magma, remnants of the feeder pipes of former volcanoes. Necks and plugs are cylindrical and usually vertical.

All the foregoing forms of igneous rock masses may occur in connection with each other, e.g. a dike may lead into a laccolith. Because sedimentary rocks are layered, the forms of igneous

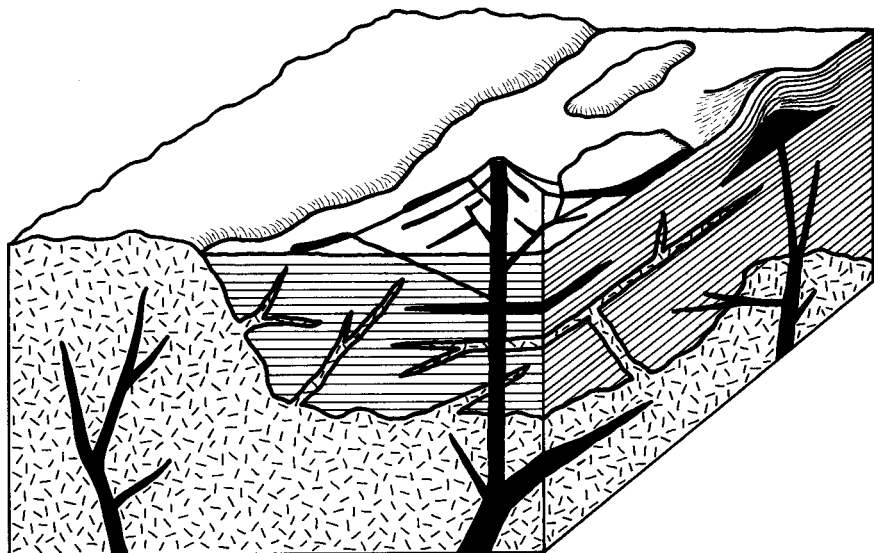


Fig. 3-1. - Extrusive and intrusive igneous rock forms. Illustrated are batholith, dikes, sill with dike feeder, volcanic neck, volcanic cone, laccolith, stock (outcrop of igneous rock in center of sedimentary area), flow. Lava (black) is younger than either sedimentary rocks or batholith.

masses are most easily recognized when they intrude sedimentary rocks. When magmas intrude igneous rocks, the form is more difficult to recognize because the contact between the two igneous rocks is often vague. Any body of igneous rock intrusive into other rocks is called an intrusion; the surrounding rocks are then said to be intruded. If the intrusive cuts across the structure of the intruded rock, it is said to be discordant; if it follows the structure, accommodating itself to bedding, schistosity etc., it is said to be concordant. (Schistosity is the structure peculiar to schists. See metamorphic rocks).

Extrusive Igneous Rock Forms

Extrusive rock masses are those which form from molten magma forced to the surface of the earth. Magma is usually called lava when it flows on the earth's surface.

VOLCANOES - Volcanoes are dome or cone shaped surface features that have been built by lava and/or other volcanic material; they range in size from very small mounds to lofty mountains. The funnel-shaped opening of the top, from which the lava flows, or from which gases and particles of volcanic material erupt, is called the crater. If gas pressure increases within the magma, it may eventually cause a violent eruption or a series of eruptions. If the gas escapes steadily from the magma, the eruptions are less violent. Steam is the most common volcanic gas. If little gas is present and the lava is quite fluid, only a slow upwelling and outpouring occurs.

Shield volcanoes - Shield volcanoes are formed when layer upon layer of fluid lava is extruded in a comparatively quiet manner with no violent explosions. Shield volcanoes do not form sharp peaks but assume a broad, domal shape, as the lava flows outward from the point of eruption.

Cinder cones - Cinder cones are built by eruption of fragmental materials. The sizes

of these fragments vary from ash to the gravel-sized particles known as lapilli to the larger particles called bombs. Cinder cones form sharper peaks than do shield volcanoes.

Compound Volcanoes - Compound volcanoes are built of alternating layers of solidified lava and fragmental material. Many large volcanoes are so constructed. The popular conception of a volcano, with its graceful concave flanks, is that of a compound volcano. Vesuvius, Shasta, and Ranier are examples.

FISSURE FLOWS - Another type of extrusive is a fissure flow; the lava flows from a fissure or crack and sometimes covers a large area. If the lava is quite fluid, it may flow for long distances; but if the lava is more viscous, it hardens quickly and forms thick sheets. The Columbia Plateau is an example.

Classification Of Igneous Rocks

For the purpose of this book, the classification of igneous rocks is based on two variables: the mineral content and the texture (particularly grain size). Because both of these variables are gradational, the mineralogical and textural boundaries separating one igneous rock from another are arbitrary. Thus, granite grades into syenite compositionally and into rhyolite texturally. Only by carefully studying and comparing representative specimens of the various types can the prospector become proficient in identifying igneous rocks. When studying the rock specimen, he must be careful to make certain that the specimen is a fresh sample, since near the surface of the earth, the rocks are somewhat weathered and the contained minerals may be altered as a result.

MINERAL CONTENT - The minerals in a particular igneous rock are divided into three groups based on the relative amounts of each mineral present. The first group of minerals are the essential minerals, which form most of the rock and generally determine the basic name of the rock; for example, coarse grained igneous rock composed primarily of quartz and feldspar is defined as granite. The second group of minerals are the accessory minerals, which form only a small percentage of the rock. Accessory minerals may be used to name a rock more precisely; that is, if hornblende is a conspicuous accessory mineral in a granite, it would be called a hornblende granite. The third group of minerals found in igneous rocks are the microscopic accessories. As the name indicates, these minerals occur as very small grains visible only with a microscope; for ordinary field work this third group of minerals is ignored in identifying rocks.

To describe most igneous rocks, the principal rock-forming minerals - most of them silicates - must be known. Many other minerals occur in rocks, of course, but they are in small amounts, and ordinarily do not affect the classification.

In general, there are two broad classes of minerals, the light colored, lighter weight ones and the dark heavier ones. Those of the first class are called felsic (coined from the words "Feldspar" or "felspathoid" and "silica." Salic (from "siliceous" and "aluminous") is also descriptive of light colored minerals, but is a chemical term and should not be applied to actual minerals.

The second (dark heavy) class of minerals is called ferro-magnesian, mafic, or femag (from ferro and magnesian). These are the minerals high in iron and magnesium. Femag from "ferro-magnesian" is a chemical term corresponding to salic. The most common rock forming minerals falling into these two classes are:

Felsic

Quartz
Orthoclase } feldspars
Plagioclase }
Nepheline } feldspathoids
Leucite }

Mafic

Micas (except muscovite)
Pyroxene (augite)
Amphibole (hornblende)
Olivine
Iron Oxides

Augite and hornblende are the most widespread and common representatives of the mineral groups pyroxene and amphibole. When the terms pyroxene or amphibole are used, augite or hornblende are usually the specific minerals meant, although other minerals of the group are not necessarily excluded.

Most rocks consist of minerals from both groups; if the rock consists predominantly of felsic minerals, it is light colored. There are several terms used to describe such rocks; felsic, acidic, acid, silicic, siliceous, persilicic, all meaning the same thing. Of these, "felsic" and "persilicic" are probably preferable, but "acidic" is deeply rooted in the terminology and is the most commonly used. Rocks in which the mafic minerals predominate are called ferro-magnesian, mafic, femag, subsilicic, or basic. Of these terms, "basic" is the least desirable, but it too is deeply rooted and commonly used. Rocks may range from extremely felsic (pure quartz) to extremely mafic (iron oxide, or even native

terrestrial iron and iron-nickel meteorites). Rocks composed almost entirely of dark colored minerals are called ultramafic or ultrabasic.

Another method of describing the mineral composition of igneous rocks, differing somewhat from the felsic-mafic classification, divides them into oversaturated, saturated, and undersaturated rocks. (The saturation refers to silica). Saturated minerals are those of high silica content which will not react with quartz to form a mineral of higher silica content. Such minerals can exist in the presence of free silica (the mineral quartz). Unsaturated minerals are certain minerals of low silica content which develop in an environment deficient in silica. These minerals usually are not found with free quartz, because during their formation, they react with all the silica present and still are left "unsaturated." If more silica were available, the minerals would combine with it to form saturated minerals; and if even more silica were available, some free quartz would form from what was left over.

The oversaturated rocks contain free silica (quartz) along with saturated minerals. The saturated rocks contain only saturated minerals. Undersaturated rocks contain some unsaturated mineral or minerals, either by themselves or with saturated minerals—never with appreciable amounts of quartz. (It should be understood that the quartz referred to is part of the rock and not quartz segregated into veins, which may have been introduced long after the rock solidified). Some of the most common rock forming minerals in each class are as follows:

Saturated Minerals

Feldspars
Pyroxenes (augite)
Amphiboles (hornblende)
Micas
Magnetite
Tourmaline

Unsaturated Minerals

Sodalite
Leucite
Nepheline
Olivine

} feldspathoids

Two other terms, not however, commonly used, describe igneous rocks on the basis of color: leucocratic (light colored) for felsic rocks, and melanocratic (dark colored) for mafic rocks.

Two pairs of minerals which are difficult to distinguish often determine the variety of the rock. These pairs are orthoclase and plagioclase, and hornblende and augite. The following characteristics, some of them from Kemp's Handbook of Rocks helps in separating them.

Orthoclase

Not striated; often shows
Carlsbad twinning
Stubby crystals
Flesh colored to white
Pearly to chalky luster, rarely
vitreous
In light colored rocks
In rocks of felsic composition

Plagioclase

Striated on some cleavage faces
Lath-like or platy
White to gray
Vitreous to pearly luster
In intermediate to dark colored rocks
In rocks of intermediate to mafic
composition

Augite

Crystals stubby, 8 sided
Cleavage angle near 90°
Dull, submetallic luster
Usually greenish black
In intermediate dark colored
rocks

Hornblende

Crystals elongated, 6 sided
Cleavage angle near 60° and 120°
Silky to vitreous luster
Usually solid black
In light colored rocks

In igneous rocks, certain combinations of minerals tend to associate with each other, while other combinations do not. Investigations have shown that as the temperature of a rock melt begins to drop, minerals tend to form in a certain order. Among the mafic minerals the order is olivine, pyroxene, amphibole, biotite. Among the plagioclases, the order is calcic plagioclase (anorthite, calcium aluminum silicate); Calc-sodic plagioclase (more calcium than sodium); sodic-calc plagioclase (more sodium than calcium); and sodic plagioclase (albite, sodium aluminum silicate). These two groups may form simultaneously. Orthoclase, muscovite, and quartz form last, at the coolest temperatures. This order of crystallization helps to explain the mineral associations mentioned above. Early forming mafic minerals of one group tend to be associated in rocks with the early forming minerals of the other group; i.e., pyroxene with calc-sodic

plagioclase to form gabbro. In the more felsic rock diorite, amphibole is associated with sodic-calc plagioclase.

It is not uncommon for a single magma to give rise to a mass of igneous rock which varies in mineralogical composition from place to place. Early formed crystals may sink to the bottom of the magma chamber, leaving a liquid of different composition in the upper region of the chamber. When completely crystallized, such a mass shows vertical compositional variation. On the other hand, due to earth movements, the liquid portion of a partly solidified magma may be squeezed off into some adjoining area, resulting in at least two rocks of different composition forming from the same magma. These are but two of the mechanisms by which more than one igneous rock may develop from a single originally homogenous magma. It is clear that variations in mineralogical composition do not necessarily imply separate intrusions.

TEXTURE - Igneous rocks are also classified according to their textures as well as to their mineral contents. The texture of an igneous rock is determined by the size of mineral grains, the shape of the grains, and the manner in which the grains are fitted together. In particular, the size of the grains is used in the classification of igneous rocks.

The rate of cooling of a magma largely determines the texture of the resulting rocks. Magmas deep within the earth cool very slowly and develop large crystals. Coarse-grained rocks are formed in this way. Phanerites are coarse grained rocks in which most of the crystals or grains can be distinguished with the naked eye in hand specimens.

Other igneous rocks cool more quickly, especially those formed near or at the surface of the earth. A hand lens or microscope must be used to distinguish the crystals in such rocks, which are called aphanites.

Some extruded magmas cool so rapidly that no minerals have time to form. These rocks are the volcanic glasses.

Because the grain size depends upon the rate of cooling, which in turn depends chiefly on the depth at which the rock is crystallizing, some geologists refer to rocks of a certain grain size by terms descriptive of the depth at which they are believed to crystallize. Thus, coarse grained rocks are plutonic, and fine grained to glassy rocks are volcanic; those in between are hypabyssal. Rocks with large grains of almost equal dimensions and poor crystal boundaries are sometimes said to have granitoid texture, named after granite, the most common rock exhibiting this texture.

In many igneous rocks most of the grains are the same size. These rocks are equigranular. Other rocks, have both large and small grains; the large grains are called phenocrysts and the fine grained material is called the groundmass or matrix. This combination of phenocrysts and groundmass results in a porphyritic texture, and rocks having this texture are called porphyries. It is not the absolute size of the crystals, but the difference in size between phenocrysts and groundmass that determines that a rock is a porphyry.

As igneous rocks vary both in mineral content and in texture, obviously some rocks have the same composition and different texture; others, the same texture and different composition. In fact, most igneous rocks have equivalents with the same composition but different texture. Rocks which vary only in texture but not in composition are said to belong to the same clan. Each clan has a phaneritic (visible grained) representative and an aphanite representative. Examples of clans are gabbro (coarse grained) and basalt (fine grained); granite (coarse grained) and rhyolite (fine grained).

There are also rocks of intermediate grain size-sometimes called "sugary grained." These usually form in dikes, and defy exact classification in the field. Two useful terms for these rocks are aplite, the felsic; and lamprophyre, the mafic variety. The term dolerite is also sometimes used for dark rocks of intermediate grain size. Dolerite, however, is at other times applied to dark rocks of any texture; the term should be used with caution.

Types Of Igneous Rocks

GRANITE-RHYOLITE CLAN - Essential minerals: quartz and orthoclase or microcline.

Accessory minerals: biotite, muscovite, amphibole, pyroxene, plagioclase, tourmaline, garnet, magnetite.

Granite occurs in batholiths or stocks. It is light colored, usually light gray to pink, although some yellow, blue, or darker red varieties are known.

A representative granite might contain 30% quartz, 30% orthoclase, 20% sodic plagioclase, and the rest dark minerals.

SYENITE-TRACHYTE CLAN - Essential minerals: Orthoclase, sodic plagioclase (albite), no other mineral over 5%.

Accessory minerals: Amphibole, pyroxene, biotite, plagioclase, olivine, muscovite, corundum, tourmaline, garnet, magnetite.

Syenite differs from granite in having little or no quartz. The average syenite might contain 80% feldspar, 50% to 70% of which is orthoclase, and 20% dark minerals: hornblende, biotite, and pyroxene.

Closely allied to this clan is the nepheline syenite-phonolite clan. These rocks

are rare and difficult to distinguish. They resemble syenites, but have in addition nepheline or other feldspathoid minerals. Since feldspathoids are unsaturated minerals and cannot exist with quartz, a presence of quartz in a rock immediately rules out its being nepheline-syenite. Nepheline weathers faster than feldspar, sometimes leaving pits in the rock. Feldspathoids also give the rock a greasy luster. Essential minerals are orthoclase and nepheline. Accessory minerals are plagioclase, pyroxene, amphibole, olivine, and biotite. The average nepheline syenite might consist of 80% felsic minerals, over 15% of which is nepheline, much orthoclase, a little plagioclase, traces of other feldspathoids; and a remaining 20% dark minerals.

DIORITE-ANDESITE CLAN - Essential minerals: medium plagioclase.

Accessory minerals: biotite, pyroxene, quartz, mica, olivine, corundum.

The average diorite might contain 65% plagioclase and 35% dark minerals; hornblende, biotite, or both, with a small amount of pyroxene. Note: Some authors differentiate between diorite and gabbro on the basis of the plagioclase, and some on the basis of dark minerals. Diorite contains medium plagioclase and hornblende; gabbro contains calcic plagioclase and augite. As it is difficult to distinguish one plagioclase from another in a hand specimen, it is best to use the dark minerals as a criterion.

GRANODIORITE-RHYODACITE CLAN, QUARTZ DIORITE-DACITE CLAN, MONZONITE-LATITE CLAN, QUARTZ MONZONITE-QUARTZ LATITE CLAN - Granite is essentially quartz and orthoclase, and diorite is essentially plagioclase with subordinate hornblende. Granodiorite, intermediate between them, contains quartz, orthoclase, plagioclase, and accessory mafic minerals.

A decrease in the amount of orthoclase and quartz with corresponding increase in amount of plagioclase, gives quartz diorite. Both granodiorite and quartz diorite are intermediate between granite and diorite, granodiorite being more like granite and quartz diorite more like diorite. The aphanitic equivalent of quartz diorite is dacite, of granodiorite, rhyodacite.

Rock containing orthoclase and plagioclase, each comprising one third to two thirds of the total feldspar, with accessory mafic minerals, is a monzonite. Monzonite resembles granodiorite, except it contains less quartz.

If the rock contains approximately equal amounts of orthoclase and plagioclase, as well as quartz and mafic minerals, it is a quartz monzonite. Its aphanitic equivalent is a quartz latite.

Quartz monzonite and granodiorite are closely associated. All of these rocks grade into each other.

GABBRO-BASALT CLAN - Essential minerals: Calcic plagioclase (toward the anorthite end of the plagioclase series).

Accessory minerals: pyroxene, olivine, mica, amphibole, magnetite, ilmenite, quartz, alkali or sodic plagioclase.

In the field it is best to decide between gabbro and diorite by the dark minerals. (See diorite). A typical gabbro might be half labradorite plagioclase and half dark minerals: commonly augite, olivine, and magnetite. Norite is a special gabbro containing pyroxene crystallized in the orthorhombic system, and anorthosite is one composed mostly of dark plagioclase. Diabase is a gabbro or basalt containing lathlike plagioclase crystals.

PERKNITE-AUGITITE CLAN - Essential minerals: pyroxene or amphibole, or both, less than 10% felsic minerals.

Accessory minerals: micas, magnetite, ilmenite, spinel, apatite, garnet, olivine, feldspars.

The average perknite is over 90% mafic minerals. If dominantly pyroxene, it is called pyroxenite. If dominantly hornblende, it is hornblendite. "Perknite" is not a common term; "pyroxenite" or "hornblendite" are usually used. (Do not use "amphibolite" for "hornblendite", amphibolite is a metamorphic rock). The fine grained equivalent of pyroxenite is augite.

PERIDOTITE-PERIDOTITE BASALT CLAN - Essential minerals: olivine, and less than 10% felsic minerals.

Accessory minerals: pyroxenes, amphiboles, mica, magnetite.

Peridotites cover a wide range of composition, from pyroxenite (predominantly pyroxene) to dunite, predominantly olivine. "Peridotite" usually means a rock composed of olivine and pyroxene; when the olivine approaches 100%, the rock is called "dunite". A special peridotite with a porphyritic texture occurs in South Africa. It is called kimberlite, and is famous for the diamonds it contains. The aphanitic equivalent of peridotite is peridotite basalt, sometimes called limburgite.

In this discussion of igneous rocks, common igneous phaneritic rocks, ranging from granite to peridotite, have been described, and their fine grained aphanitic equivalents named. There are in addition, several points to remember in dealing with igneous rocks. Usually a definite determination cannot be made without a microscopic examination, especially among the aphanites. It is common to call a light colored fine grained igneous rock a felsite, and a dark fine grained one, basalt or trap. The general terms aplite, lamprophyre, and dolerite, for rocks of intermediate grain size, have already been mentioned. All these terms, felsite, basalt, trap, aplite, lamprophyre, and dolerite are sometimes used to tentatively

classify a rock in the field pending more positive identification. A rock with porphyritic texture may be called porphyry, prefixing the rock type name, as granite porphyry, or rhyolite porphyry; it can usually be assigned to a clan. It should also be remembered that there are multitudes of local special rock names which cannot be mentioned here. A list of these rock names can be found in the back of Kemp's Handbook of Rocks. In the field even the coarse grained rocks may defy classification; and it is common to say "granitic rock" for the light colored ones, meaning granite, syenite, monzonite, quartz diorite, etc., or "gabbroic rocks" meaning the dark ones.

PEGMATITES - Pegmatite is a term given to rocks that have very coarse grains. These grains vary in size from slightly larger than those in phanerites to crystals many feet long. Pegmatites usually have a composition approaching that of granite. Some of the rarer minerals which are often found in pegmatites are beryl, spodumene, tourmaline, topaz, columbite, and tantalite. Pegmatites sometimes occur in dikes around the edges of intrusions.

VOLCANIC TUFF - Volcanic tuff is cemented volcanic dust and ash. Tuff is made up of fragments of glass, minerals or rocks that have been forcibly ejected from a volcano.

VOLCANIC BRECCIA - Volcanic breccia is a rock made up of cemented volcanic fragments larger than ash and tuff (larger than 1/2 inch or so in diameter). This rock is sometimes called agglomerate.

Volcanic tuffs and breccias are sometimes classified as sedimentary rocks.

All the material ejected from volcanoes is called pyroclastic material.

GLASSES - (Contain no crystals). Glasses are formed when lava cools very quickly. Crystals have no time to form; therefore strictly speaking, glasses are composed of atoms and molecules rather than minerals.

Obsidian - Tachylite - Obsidian and tachylite are natural glasses. Obsidian is usually dark, but can be any color. Most often it is felsic in composition. If the glass is definitely basaltic in composition, it is tachylite.

Pitchstone - Pitchstone is similar to obsidian, but has a resinous luster.

Vitrophyre - Vitrophyre is a porphyry with a glass groundmass.

Pumice - Pumice is volcanic glass containing many cavities due to gas forming during sudden decrease in pressure. The cavities are called vesicles. Pumice is light enough to float in water.

Table of Igneous Rocks

To help fix in mind variations in mineralogical composition and texture which determine the rock, a table has been arranged (Table 3-1) showing mineralogical variation horizontally and textural variation vertically. Composition varies from felsic to mafic toward the right, and texture varies from coarse to fine downward. Fig. 3-2 illustrates common intrusive rocks and minerals from which they are formed.

which they are formed.						COMPOSITION							
Light Colored						Dark Colored							
T E X T U R E	COARSE	Feldspar + Quartz	Feldspar - Quartz	Feldspar + Amphibole	Feldspar + Pyroxene	Pyroxene, Amphibole							
		GRANITE	SYENITE (Nepheline-Syenite, Monzonite)	DIORITE (Quartz-Diorite, Granodiorite)	GABBRO	ULTRAMAFICS		Perknite, Peridotite					
		RHYOLITE	TRACHYTE (Phonolite, Latite)	ANDESITE (Dacite, Rhyodacite)	BASALT	AUGITITE, etc.							
	FINE	FELSITE			BASALT or TRAP								
		GLASSY	OBSIDIAN PUMICE PITCHSTONE			TACHYLITE							
	FRAGMENTAL		TUFF and BRECCIA										
Table 3-1 TABLE OF IGNEOUS ROCKS													

With the exception of tuff and breccia, any of the above rocks may be of porphyritic texture, e.g. granite porphyry, basalt porphyry. Glassy rocks showing porphyritic texture are called vitrophyres, e.g. obsidian vitrophyre. Aplites are light colored dike rocks of sugary texture; lamprophyres are their dark equivalents. Dolerite is sometimes equivalent to lamprophyre, sometimes applied to all dark igneous rocks.

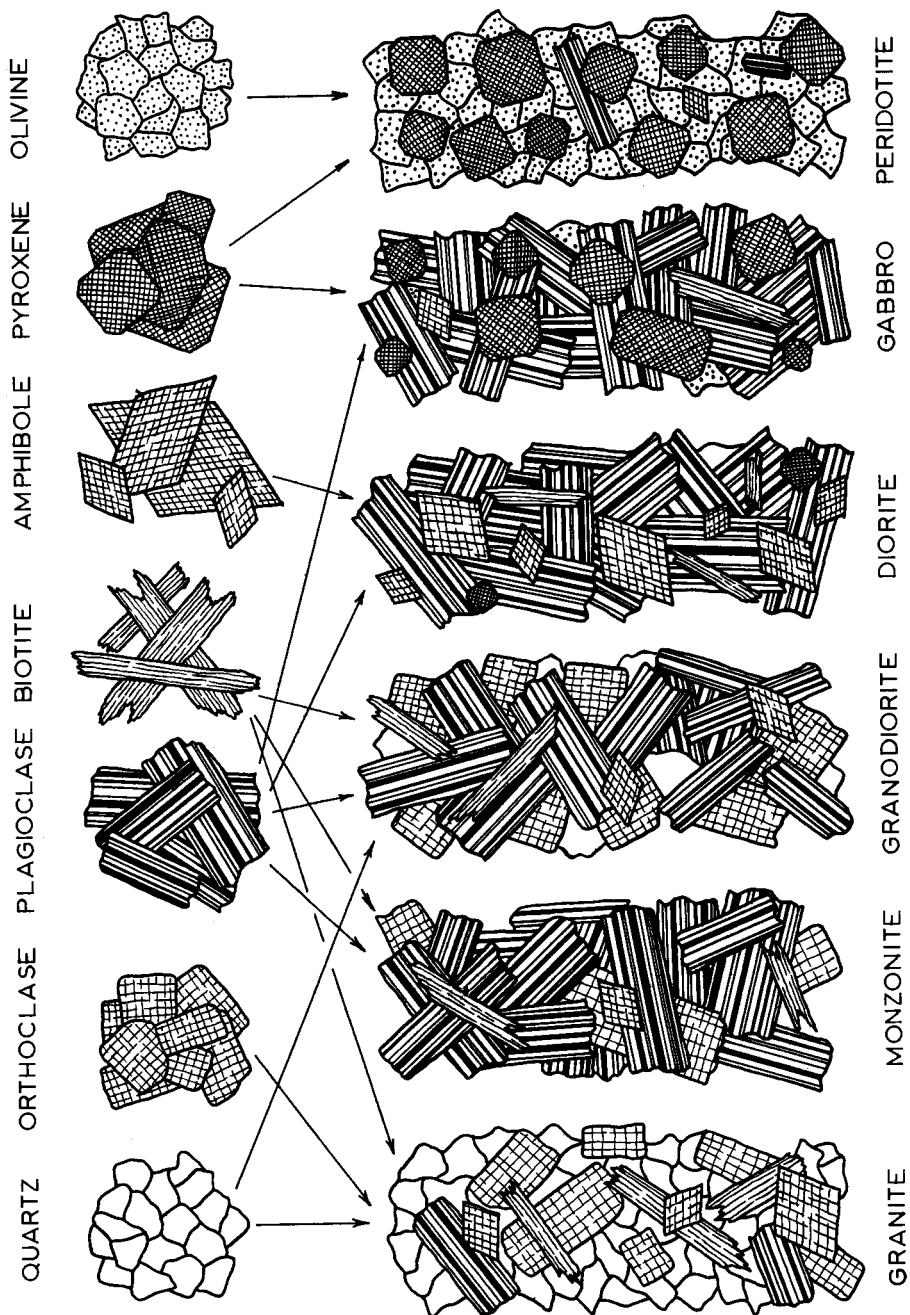


Fig. 3-2. - Combinations of Minerals That Compose Igneous Rocks (Modified from Strahler)

SEDIMENTARY ROCKS

Sedimentary rocks are the second great class of rocks. They are formed by the compaction of sediments, the products of mechanical or chemical disintegration of the rocks of the earth's crust. Some of the chemical processes that produce sediments consist in part of the life cycles of plants and animals. As a means of classifying sedimentary rocks, the processes of disintegration are divided into four groups; residual (mechanical disintegration and accumulation in place), mechanical (mechanical disintegration, transportation, and deposition), chemical (dissolving and redepositing of material), and organic (collected in the bodies of organisms).

When the sediments lie loosely upon the earth, as gravel, sand, silt, soil, etc., they are said to be unconsolidated, and this loose covering of the earth is called the regolith or more commonly the unconsolidated cover. When the unconsolidated sediments harden into sedimentary rocks through compaction and cementation, they are said to be consolidated, indurated, or lithified. Consolidation takes place in a number of ways. Clay particles may be attached to each other by pressure ("welding") or by the introduction of a binding agent. Coarser materials are cemented together by a mineral deposited by percolating water. The cementing minerals are usually calcite, iron oxide, or silica, although others often are observed. (In the north ice sometimes forms the cementing mineral - see Chapter 6).

Sediments in which the different sized particles are separated are said to be sorted; those in which particles of different sizes are mixed together are nonsorted or unsorted.

In general, three fundamental types of sedimentary rocks formed by residual or mechanical means are recognized, classified separately on the basis of grain size. The large grained rocks composed of consolidated gravel are called conglomerates, or if composed of angular fragments, breccias. The intermediate sized grains, sand, make up the sandstones. The third class is made up of fine grains of silt, mud, or clay, and is called shale, if it splits easily, or mudstone, if massive. Rocks composed of silt are sometimes classified intermediate between sandstones and mudstones, and called siltstones. Mudstones composed of clay are called claystones. Sedimentary rocks that are composed of gravel or large angular fragments are called rudaceous rocks. Those composed of sand are called arenaceous rocks, and those composed of clay or mud are called argillaceous rocks. Occasionally sedimentary rocks of mechanical origin may contain grains of different sizes, so that they can be placed in either of two categories. Such rocks of uncertain classification are encountered much less frequently in the sedimentary than in the igneous rocks.

Sedimentary rocks deposited in seas are called marine sedimentary rocks. Those deposited on land, and this includes fresh water bodies on the land, are called terrestrial sedimentary rocks. The terrestrial sedimentary rocks sometimes are red due to the oxidation of included iron. These are sometimes called red beds.

Sedimentary Rocks of Residual Origin

When an original rock surface weathers, most of the products of weathering are washed away. On some surfaces of low relief underlain by relatively insoluble material, a portion remains behind as a residue. The accumulation and consolidation of this material form sedimentary rocks of residual origin.

Sedimentary rocks of residual origin include conglomerates, sandstones, and shales or mudstones. Certain rocks, notably granites, weather in place to sand which then may become consolidated into sandstone. Conglomerates and breccia formed in place almost always must derive their constituents from the weathering of earlier conglomerates and breccias.

Although sands and gravels are occasionally observed in residual sedimentary rocks, clay forms the most important rocks in the class. In tropical and sub-tropical countries, rocks containing aluminum and iron, instead of forming clay, weather to soils called laterite. Laterite consists of hydrous oxides of iron and aluminum plus some silica and other impurities. If rich in iron or aluminum, laterite may be ore. (See definition Chapter 7). Such aluminum ore is called bauxite. The laterite soil itself may be thought of as a residual unconsolidated rock.

Sedimentary Rocks Of Mechanical Origin

WATERLAID SEDIMENTS - Material is washed from the uplands and deposited in lowlands in an unending process. Because gravels are transported much less easily than sands and clays, naturally most gravels are found in stream beds or in outwash fans, rather than in basins far from the source. Most conglomerates, then, are of fluvial (stream-laid), rather than of lake or marine origin. Conglomerates are formed also by the gradual encroachment of the sea upon the land, but such conglomerates are limited to less than 100 feet in thickness since the waves are relatively ineffective below that depth. Conglomerates composed of pebbles of the rock immediately below them are called basal conglomerates.

Breccia, a conglomerate type rock made up of cemented angular fragments, may be formed in the same way as conglomerate, the only difference being that the fragments underwent less transportation and consequently less wear. Often breccias are formed from talus material which has undergone no water transportation; occasionally breccias are formed on coasts where angular blocks fall into the sea and are protected from wear by enclosing mud. Volcanic breccia or agglomerate has already been mentioned as an igneous rock. Tectonic breccia is formed by the crushing action of earth movements; collapse breccias by collapse of the roof of some cavity.

Sands are found wherever gravels accumulate; they may also be carried farther than gravels and are then found on deltas and the margins of lakes and seas. Many different sandstones have been named, depending upon the material of the sand or of the cementing material. A coarse sandstone with angular grains is a grit. Sandstone containing abundant feldspar, usually derived from granite, is called arkose; and a gray sandstone containing a large proportion of silt or mud, is called graywacke. Quartz grains, when completely and solidly cemented with silica, form sedimentary quartzite. (See quartzite under metamorphic rocks). In addition to these geological terms, several names have developed through the use of sandstone in the building trades, e.g., flagstone, brownstone.

The argillaceous rocks - shales and mudstones - are formed from material which has undergone the greatest amount of weathering and transportation. Muds and silts are deposited in streams, but more often are swept into basins - lakes or seas, where the finest material drifts the farthest away from shore to settle as a very fine sediment. (The seas are the greatest repositories of the argillaceous rocks). Clay, while usually of residual origin, often is water laid, especially in areas of glacial action. The moving glacier grinds rock into clay sized particles, which are washed out by streams emanating from the ice. Black and blue clays are produced from marine muds; marl is a clay rock, containing much calcium and magnesium carbonate.

GLACIER-LAID SEDIMENTS - Although much material of glacial origin is transported down streams and loses its glacial identity (see preceding paragraph), other glacial deposits are easily identified as such because of their poorly sorted, jumbled appearance. At low elevations, glacial clay, pebbles, sands, and boulders may be found mingled together; higher up, much of the clay may be removed by water, leaving a coarser product. This material is called till, and when consolidated, tillite.

WINDLAID SEDIMENTS - The dust which blows away from dry areas sometimes builds up great deposits, known as loess. Loess deposits are often difficult to distinguish from water-laid deposits by casual observation, but loess lacks the stratification and variation in size of water-borne sediment. Consolidated loess is rare. Sand dunes are hillocks of sand that has blown from beaches, stream bars, or desert areas, and piled up by the wind.

Sedimentary Rocks Of Chemical Origin

Chemical sediments are those formed by the precipitation of material held in chemical solution. The oceans, and to a lesser degree, lakes and ground waters, are great natural reservoirs of dissolved mineral matter. When conditions become suitable, these dissolved minerals precipitate and accumulate, either separately or in combination with one another.

The rocks of chemical origin naturally are divided on the basis of composition. Because chemical precipitates are very fine grained, the texture of such deposits usually shows less variation than that of other rocks, although the evaporation of solutions sometimes produces large crystals.

There are, however, certain special forms and structures which sometimes impart characteristic textures even to uniformly fine grained rocks.

TEXTURES AND STRUCTURES - Sometimes crystallization starts from a center, and grows radially, as in stalactites; or the mineral may grow around a nucleus, forming concentric spheres. If of the size of fish roe, these spheres are called oolites; if the size of peas, they are called pisolites.

Concretions are inclusions of composition different from the enclosing rock; that is, they are concentrations of minor materials collected by percolating water and deposited around some center. The well known flint and chert nodules in chalk are concretions. **Secretions** are accumulations of material deposited in empty cavities in rocks. **Druses** are cavities lined with minerals identical to those in the enclosing rocks. When these hollow inclusions are separable from the rock, they are geodes, although a geode need not be of the same material as the surrounding rocks. **Dendrites** are delicate tree-like secretions of iron and manganese oxides deposited along cracks in rocks. **Deoxidation spheres** are concentric spheres of lighter color within red rocks, caused by the reduction of iron around fragments of organic material and the leaching away of the more soluble reduced form.

Certain phenomena occur in colloids, which are dispersions of very tiny particles (on the order of 100 molecules in diameter). When colloids solidify, they produce at first amorphous (non-crystalline) minerals such as opal and limonite, which may change to fibrous or crystalline minerals of like composition. The rhythmic banding of certain rocks, such as agate, is a

colloid phenomenon; fine material diffusing through a colloid encounters other dispersed material with which it reacts and precipitates to form a band. After the originally enclosed material has been used up in the vicinity of the band, the new material must proceed farther to find enough material with which to react. In this way several bands may be formed.

The common sedimentary deposits of chemical origin are composed of (1) silica, (2) carbonates, (3) iron compounds, and (4) salts.

SILICEOUS - Silica in the form of quartz is virtually insoluble, but silica, liberated during the weathering of rock forming silicates, can be transported in solution and deposited around springs in the form of siliceous sinter. Flint and chert distributed as concretions in limestone and other rocks compose a good share of the siliceous deposits of chemical origin. Chert also occurs as massive replacements of limestone.

CALCAREOUS - Carbonate rocks include limestone (calcium carbonate) and dolomite - the mineral dolomite (calcium magnesium carbonate). Although most limestones and some dolomites are formed by organisms, certain fine grained varieties are the products of chemical action. Waters percolating through limestone and dripping in caves form stalactites, icicle-like hanging features, and stalagmites, the material that accumulates on the cave floors. When banded and capable of taking a good polish, stalagmite is called Mexican onyx. (True onyx is bonded chalcedony). Limestone deposited around springs is called calc-sinter or travertine. In arid regions, calcium carbonate is sometimes brought to the surface by the evaporation of ground water and deposited as a limestone called calcareous caliche. It is probable that much limestone has been precipitated directly from the sea by chemical means, but it would be difficult to separate limestone of this origin from that due to the action of living organisms.

FERRUGINOUS - Deposits of rocks containing much iron are very important commercially because from these deposits iron ores are formed by local enrichment. Iron is in solution mainly as bicarbonate, which is easily converted to carbonate. Under oxidizing conditions, iron is precipitated as the hydroxide, forming bog iron ore, and under reducing conditions as the carbonate, yielding siderite. Iron silicates deposited in ancient seas with chert and jasper form the source rock for the iron ores of the Lake Superior area.

SALTS - Salts include the chlorides, carbonates, sulfates, nitrates, and borates of sodium and potassium, and the sulfates of calcium and magnesium. Most rocks composed of these minerals are deposited from sea water which has become concentrated by evaporation under special conditions. This group of rocks, called the evaporites, includes such rocks as salt, gypsum, and anhydrite. Apparently the conditions required for the formation of these rocks are an arid climate and an arm of the ocean almost isolated from the main sea. As evaporation of the water proceeds, more and more material is concentrated in the brine and eventually deposition occurs.

Salt is sodium chloride, the mineral halite. Pure salt is colorless, but impurities may color it shades of brown, blue, yellow, or red.

Gypsum is calcium sulfate and water ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). Depending upon the shape and size of the crystals, gypsum occurs in several varieties. Massive gypsum, called alabaster, is composed of very small crystals tightly packed together. Fibrous gypsum, or satin spar, is composed of long, thin crystals lying parallel to each other. Selenite is well crystallized gypsum occurring in fairly large separate crystals. Gypsum is usually white or gray, but may be red or brown. Selenite is colorless.

Anhydrite is calcium sulfate (CaSO_4). It is usually white in color, massive, and closely resembles gypsum, to which it alters very rapidly when exposed to the atmosphere.

Caliche is a term for an impure evaporite product consisting partly of calcium carbonate (CaCO_3) or sodium nitrate (NaNO_3), found only in arid climates.

There are several other rocks which form as part of the evaporite series, but they usually are not preserved over long geologic periods of time. The deposits formed in basins in desert regions such as Death Valley, California, may be of considerable economic value. In this region, the infrequent rains wash quantities of material into the basins. During the long dry spell which follows, all of the water is evaporated and all of the dissolved materials are deposited. In this way, large quantities of borax and related minerals have been formed.

Sedimentary Rocks Of Organic Origin

Many of the organisms that live in the ocean produce sediments in one way or another. Such sediments are called organic sediments. Some organisms, by removing various chemicals from the sea water during their life processes, change the concentration of dissolved materials so that deposition results. Organisms may also use some of the materials dissolved in sea water as constituents of their skeletons and, upon dying, contribute them to a sedimentary rock. Clam shells and fish bones are typical of such contributions. Another group of organisms, the microscopic forms such as foraminifera, algae, and diatoms, live in the oceans in vast numbers and their skeletons may be abundant enough to form extensive deposits.

CALCAREOUS - The organic calcareous rocks are called limestones; they are composed chiefly of calcite, but sometimes contain magnesium. Chalk is limestone formed from the

accumulated tests or skeletons of foraminifera. Coral is limestone built up from the skeletons of coral animals.

IRON-BEARING - Certain bacteria have the power of extracting iron from solution and depositing it as iron oxide around themselves. Much bog iron ore is due to these bacteria, but chemical precipitation also operates, so that the deposits are of mixed origin.

SILICEOUS - The shells and tests of certain other animals and plants, radiolaria and diatoms, sometimes build up siliceous deposits in the same way that calcareous shells build up limestone. Diatomaceous earth and tripoli, used for abrasives, are pure forms.

CARBONACEOUS - Coal and peat are also organic deposits but are formed by the alteration of dead land plants. Such plants grown and accumulate under conditions which prevent the rapid decay of the plant material. A tropical climate is not essential as is evidenced by the accumulations of peat being formed at the present time in Alaska and other sub-arctic regions of the world, but all known coal beds were deposited in a warm environment.

PHOSPHATE-BEARING - The phosphate which certain marine animals concentrate in their shells and skeletons may accumulate after death to form weakly phosphatic rocks. Guano is fecal material of birds which accumulates in coastal areas. Rich in phosphate and nitrate, guano is used for fertilizer. In arid regions the nitrates and phosphates are both preserved; in less arid regions the nitrates are leached out.

TABLE OF SEDIMENTARY ROCKS

In Table 3-2 are shown the principal sedimentary rocks, their modes of formation, and their materials.

Origin	Unconsolidated	Consolidated	Remarks
I RESIDUAL	Gravel Sand Clay Tropical soils	Conglomerate Sandstone Claystone Laterite Bauxite	May contain iron
II MECHANICAL			
A. Waterlaid	Gravel	Conglomerate Breccia	(Rounded) (Angular)
1. Fluvatile	Sand	Sandstone	Arkose (contains much feldspar)
2. Lacustrine	Clay	Shale	Graywacke (contains much silt or mud)
3. Marine			
B. Glacier laid	Till	Tillite	
C. Wind laid	Loess Dunes	Lithified Loess (rare) Wind laid sandstone	
III CHEMICAL	1. Siliceous deposits 2. Carbonates 3. Iron 4. Salts	Siliceous Sinter, Chert, Flint Limestone, Dolomite Iron rich sediments Anhydrite, gypsum, etc.	
IV ORGANIC	Carbonates Silica Phosphates Carbonaceous Iron	Limestone, Dolomite Flint, chert, opal Phosphate rock Coal, etc. Bacterial iron ores	

Table 3-2 TABLE OF SEDIMENTARY ROCKS

Metamorphic Rocks

The third great group of rocks is the metamorphic group. The metamorphic rocks are very interesting but generally are more difficult to understand and classify than the other types of rocks. By definition, the metamorphic rocks are those which have been so altered by temperature, pressure, the action of solutions, or by a combination of these, without actually going through the molten state, that they have lost most if not all of their original characteristics. For instance, clay is deposited and compacted to form a soft shale. Later the shale is subjected

to very high temperature and pressure. The original clay minerals combine with other minerals to produce the mica minerals. All of the mica minerals are sheetlike; and if they are lined up parallel to each other, the rock tends to split along the cleavage of the mica. The rock is no longer a shale and will not split along the old bedding planes. In fact, the new rock will often split at right angles to the original bedding. Such a rock is called a slate.

Metamorphism

Metamorphism means change, and rocks can be changed in many ways. An understanding of the ways of change is necessary to an understanding of metamorphic rocks. Rocks change for the same reason that all things change; they respond to new conditions. It is not true, as is sometimes thought, that severe conditions are required to change rocks. Evidence of the change produced by oxygen and water, air and rain, is to be seen on every hand, but this change is called weathering, and modern usage tends to classify it separately from metamorphism due to extreme pressure and heat. Usually the type of minerals formed gives a clue to the type of metamorphism. Broad flat minerals denote directed pressure; equidimensional high temperature minerals denote hydrostatic pressure and heat.

Metamorphism may be evaluated on three scales: type of agency producing it, intensity or rank, and area affected.

TYPE OF AGENCY - Undirected (static) pressure. This type of metamorphism is due to deep and continued burial under a thick overburden of younger sediments. The rocks at the bottom are subjected to high undirected pressure and, also, to a temperature considerably above that existing at the surface. Such metamorphism is called load or static metamorphism. It usually occurs in conjunction with heat.

Directed pressure - This type of metamorphism without heat produces crushing and granulation by the movement of the rocks against each other. This is dynamic metamorphism. With heat, it is one of the most potent of metamorphic agents, sometimes producing a recombination of the constituents of the rock into entirely new minerals.

Heat - Heat alone may cause baking or recombination to form new minerals, or a general softening of the rock so that crystal boundaries become blurred or indistinguishable. Heat combined with pressure has already been noted.

Chemically active fluids and gases - Material given off by magma that has moved into an area may have a great effect upon the rocks of the area. Although heat and pressure can cause the existing materials of the rock to recombine into new minerals, the addition of new constituents greatly expands the number and scope of the changes that can take place. When the metamorphism is due to introduced gases, it is called pneumatolytic metamorphism; when due to hot liquids, hydrothermal metamorphism.

INTENSITY OR RANK - The intensity of metamorphism that a rock has undergone (rank) can be determined by the distortion of the minerals present and by the amount of the character of the original rock that is retained in the metamorphic rock. Because some rocks are more susceptible to metamorphism than others, a comparison of grade of metamorphism must always be made on the same type of rock. For instance, it would not do to compare the grade of metamorphism in two areas by using limestone in one area and quartzite in another. Limestone is easily changed; quartzite with difficulty.

A general correlation exists between the age of rocks and the degree of metamorphism, because a rock which has existed for a long time has had much opportunity to be metamorphosed. This age-metamorphism correlation is not a rule but merely a tendency.

AREA AFFECTED - The general terms regional, local, and contact are commonly used to denote the area affected by metamorphism. Regional metamorphism is the result of widespread forces, such as deep burial or mountain building. Local metamorphism is usually caused by heat and pressure from a nearby intrusion. The alteration of the country rock for a few inches to several feet on either side of a vein by hydrothermal action is another example of local metamorphism. Contact metamorphism is confined to a zone at most a few thousand feet thick around an igneous intrusion and usually is accompanied by pneumatolytic action (gases). This type of metamorphism is important in the formation of a type of mineral deposit and is discussed more thoroughly in Chapter 7.

Types Of Metamorphic Rocks

Metamorphic rocks are classified into groups depending upon the arrangement of the minerals composing the rock. One group of metamorphic rocks is composed of minerals aligned in parallel layers. These are the foliated rocks and include slate, schist, and gneiss. In the second group, the minerals lack any definite arrangement and a massive non-foliated rock results.

NON-FOLIATED ROCKS - Marble, quartzite, serpentine, and anthracite are common non-foliated metamorphic rocks.

Marble - Marble is formed when limestone or dolomite is metamorphosed. The original grains usually are combined to produce larger grains and the rock becomes very compact. A

magnesian marble results from the metamorphism of dolomite. A calcic marble is derived from an original limestone consisting mostly of calcite.

Quartzite - Quartzites are produced from sandstones when high temperature or pressure causes the cement of the sandstone and the original sand grains to react and to form larger grains. Sometimes a quartzite is defined as a sandstone so well cemented that a fracture will cut across the sand grains instead of around them. According to this definition, all quartzites are not metamorphic in origin. If the quartzite occurs with marble and schist, it is definitely a metamorphic rock; but if the overlying and underlying rocks are unaltered sedimentary rocks, then the quartzite must be of sedimentary origin. Metaquartzite has been proposed as the term for metamorphic quartzite, and orthoquartzite for sedimentary quartzite.

Anthracite - Anthracite is the final stage in the development of coal. The deposit starts as an accumulation of partially decayed plant material. Under the influence of pressure and other factors, the deposit begins to change and goes through the stages known as peat, lignite, bituminous coal, and eventually becomes anthracite. As this cycle progresses, water is driven out of the mass and other changes occur which result in the developing of a very hard compact rock. If metamorphism is extreme, the anthracite may be changed into graphite, nearly pure carbon.

Serpentine - Serpentine is nearly always a green rock, composed chiefly of the mineral, serpentine, and is produced from basic igneous rocks such as gabbro or peridotite. It is apparently formed largely by the action of hot vapors and liquids being liberated from a magma below the surface of the earth. The rock is sometimes called serpentine rock or serpentinite to distinguish it from the mineral.

Hornfels - Hornfels is a dense rock with equidimensional grains formed by contact metamorphism.

FOLIATED ROCKS - The foliated metamorphic rocks are those in which the component minerals are arranged in parallel layers or lines. As a result of this parallelism, the rocks tend to split in one direction, often into thin, flat sheets.

Slate - When a mudstone or shale is subjected to a high pressure, the new minerals formed develop with their longest dimensions parallel to a common plane. As a result the rock splits parallel to this plane. Such a rock is called a slate. The mineral grains in a slate are so small that they cannot be seen with the unaided eye.

Phyllite - Stronger metamorphism produces a phyllite, still cleavable, but containing visible mica.

Schist - If the conditions of the temperature and pressure are too severe for the formation of a slate or a phyllite, larger sized mineral grains develop. The grains are still arranged so that the large flat faces are essentially parallel to each other. The rock formed in this manner is a schist, and is composed of platy minerals. The micas are very common in the schists and largely because of these minerals the schist splits readily into sheets. These sheets are usually irregular and the fracture is not as smooth and uniform as that of a slate or a phyllite.

Gneiss - The Gneisses, some of which are formed under still more extreme conditions of heat and pressure, are characterized by the banding of light and dark colored minerals. The bands of light minerals are usually composed of quartz and feldspar. The dark colored bands are micas, hornblende, and other dark minerals. Some of these rocks break across the banding about as readily as along it, the fracture usually being very irregular. Gneiss may be formed by metamorphism of igneous rocks or of certain types of sedimentary rocks. Some gneisses are formed by granulation without excessive heat.

Under the proper conditions of metamorphism, a schist may be developed; and at a slightly later time other new minerals may form in the schist and grow to rather large sizes. Such large mineral grains are called *metacrysts* or *porphyroblasts*, the latter term being, in general, more acceptable. Garnet commonly forms in this manner. The porphyroblasts correspond to the phenocrysts in an igneous rock. In the igneous rock, the texture produced is called *porphyritic*; in the metamorphic rock, it is called *porphyroblastic*.

Table 3-3 summarizes the common metamorphic rocks.

CONCLUSION

The rocks seen at the surface of the earth today do not represent the whole of geologic time; many have been formed during the past from older rocks, and have gone through several stages in the rock making process. Igneous rocks may have been broken down by weathering and erosion to produce sedimentary rocks, or metamorphosed to form gneisses. Gneisses, in turn, may weather and erode to produce sedimentary rocks. Sedimentary rocks formed from igneous rocks may be changed into gneisses by metamorphism. Some geologists believe that under favorable conditions, metamorphism may be intensive enough to produce igneous rocks from sedimentary rocks without passing through a liquid phase. This process is called *granitization*. Thus, there is a complete cycle of rock formation and rock destruction and rocks seen today represent only a phase in this unending cycle. Fig. 3-3 attempts to represent the cycle diagrammatically.

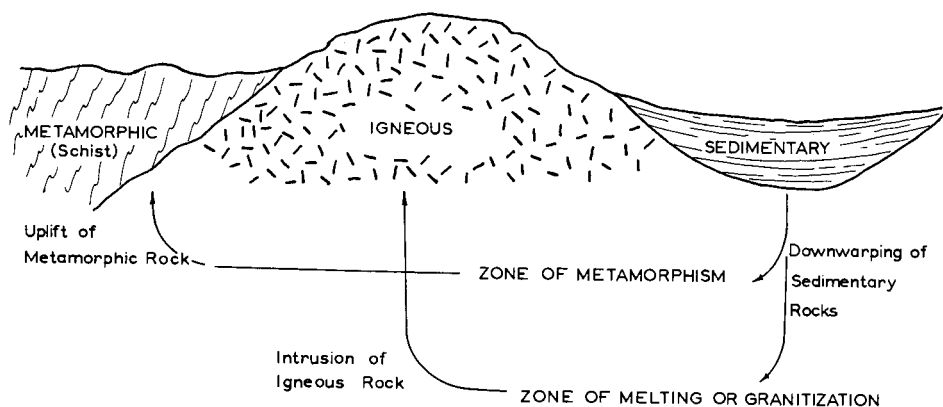


Fig. 3-3 - Cycle Of Rock Formation

METAMORPHIC ROCK CHART

FOLIATED Metamorphic Rocks - Essentially parallel grains of micaceous or prismatic minerals. May have a layered appearance due to alternating lenses that differ in mineral composition.

<u>Most Common Original Rock</u>	<u>Type and Grade of Metamorphism</u>	<u>Resulting Rock</u>
Shale, Mudstone	Dynamic, low to moderate	Slate*
Shale, Mudstone	Dynamic, moderate	Phyllite*
Shale, Mudstone	Dynamic, strong	Schist*
Sandy shale, Granite, Diorite	Dynamic, strong	Gneiss*

*These are actually textural terms used to describe any rock exhibiting the texture

NON-FOLIATED Metamorphic Rocks - Visible foliation poorly developed or absent

<u>Most Common Original Rock</u>	<u>Type and Grade of Metamorphism</u>	<u>Resulting Rock</u>
Limestone	Thermal, regional, light to moderate	Marble
Sandstone	Thermal, regional moderate	Quartzite
Coal	Thermal, regional, light	Anthracite
Basic Igneous	Dynamic, low	
Any type fine-grained rock	Contact, hydrothermal, moderate	Serpentine
	Contact, low	Hornfels

Table 3-3 TABLE OF METAMORPHIC ROCKS

References

- Grout, Frank F., 1950, *Kemp's Handbook of Rocks*, 6th Ed; D. Van Nostrand, New York
 Pirsson and Knopf, 1947, *Rocks and Rock Minerals*; John Wiley and Sons, Inc., New York
 Tyrrell, G. W., 1929, *Principles of Petrology*; E. P. Dutton and Company, New York

Chapter 4

STRUCTURAL GEOLOGY

Structural geology deals with rock structures, whether they be in sedimentary, metamorphic or igneous rocks. By rock structure is meant the positions and attitudes of rocks in place whether bedded or massive, fractured, folded or otherwise deformed.

In this book, structures of rocks are divided into two classes: those formed at the same time as the rock, original structures; and those imposed upon the rock after its formation, imposed structures.

ORIGINAL STRUCTURES

Igneous Rocks

Some of the fundamental shapes and structures of igneous rocks were described in Chapter 3. In general, igneous rocks show little structure, being more or less homogeneous. However, as will be seen in Chapter 7 some layering within an igneous body occurs while the rock is still molten (in the magma), due to the settling of heavier minerals first. This process tends to place the darker, more mafic rocks near the bottom of the body.

Another original structure of igneous rocks is due to the movement of magma toward its final position. In this movement, the magma nearest the solid walls flows slower than that more distant because of friction, and this differential movement results in the rough separation of magma into flow lines and flow layers. As their names suggest, flow lines are discontinuous lines of certain materials and flow layers are simply layers differing from one another in composition. Lines and layers form parallel to the walls, the direction of flow, and are not sharply separated from each other. The material which makes up the lines or layers may be certain minerals, rock inclusions, or gas bubbles.

Igneous rocks resulting from volcanic activity exhibit original layering or bedding that reflects the flowing of lava or raining down of pyroclastic material, ash and other fragments.

Sedimentary Rocks

By their nature, sedimentary rocks are laid down in beds, and the stratification of sediments into roughly horizontal layers is the most fundamental and important structure recognized in them. This layering, as indicated in Chapter 3, is the result of changing conditions of deposition; and the layers may grade from fine to coarse either horizontally or vertically.

Although most beds are practically horizontal when laid down, some, formed where a stream dumps its load of sediment over the edge of a bank as it enters a body of water, lie at some angle to the horizontal. The built-up sediments at such a point form a delta. Delta deposits are divided into three parts: the topset beds, lying at the grade of the stream; the foreset beds lying at the angle of repose of the material; and the bottomset beds, lying horizontally on the sea or lake floor. The topset beds grow out to cover the foresets, which in turn grow forward to cover the bottomsets as the stream pushes its delta seaward. Whenever the current slackens and dumps a load, forming little foresets and then covers them with flatter deposits truncating them at the top, cross-bedding results. Cross-bedding is also produced by wind which, because it can blow from any direction, forms more complicated patterns than does water.

Several small structures may be impressed in sediments at the time of their formation. When a shallow basin, flooded during high water, dries out, the mud left from the flood cracks into irregular polygonal blocks. If these blocks are preserved when covered again, they form mud-cracks. Ripple marks are parallel ridges formed at right angles to the direction of current or wave movement. Current ripple marks are not symmetrical, but have their steeper slopes on the downstream side. Wave ripple marks are symmetrical, and are formed only in standing water within the limit of the depth to which waves are effective in agitating water, usually 200 to 300 feet. Raindrops falling in dust or drying mud under favorable conditions may be preserved as raindrop imprints. The tracks of worms or other animals may be preserved in the same way. Casts of animals or plants, or certain durable parts of the plants or animals themselves may be preserved as fossils.

A very important structural feature is an unconformity. An unconformity is a break in the depositional sequence caused by the cessation of deposition, with or without erosion, then a resumption of deposition. The surface may have been above or below sea level during the time represented by the unconformity, but usually an unconformity signifies that the area was

above sealevel and subjected to erosion. If the beds above and below the unconformity are parallel, that is, if there has been no deformation of the lower ones before the upper ones were deposited, the feature is called a parallel unconformity or disconformity. If the lower beds have been tilted to some other angle so that the upper beds are not parallel to them, the feature is called an angular unconformity or a nonconformity. Some geologists also use the term nonconformity for an unconformity in which the erosion surface has been developed on igneous rocks subsequently buried by sediments.

IMPOSED STRUCTURES

Most rock structures have been imposed as a result of deformation at some time subsequent to the formation of the rocks. These deformations most commonly take two forms; folding and breaking. The type of deformation depends on the brittleness of the rock, the confining pressure of surrounding rocks (if deeply buried), the rate of application of pressure, and upon the competence. (A competent rock is one which can transmit a certain amount of stress; an incompetent rock is one which breaks, bends, or flows under stress).

There are two terms used continually in describing structures. The strike of a structure is the direction of a horizontal line upon its surface. The dip of the structure is the angle which it makes with the horizontal at right angles to the strike. Dip is measured in degrees and a direction such as "north" or "southwest" indicates which way the structure dips. Not only do the strike and dip give the orientation of a structure, it usually happens that the structure cannot even be recognized without knowing them. This is because whereas a small well exposed structure might be recognized, large ones which are exposed only where bedrock outcrops must be plotted on a map to be visualized. The only way to plot structures on a map is by noting dips and strikes wherever available.

Folds

Folding is perhaps the most commonly observed form of deformation. The movements, vertical and horizontal, which are continually going on somewhere in the world to maintain balance have already been discussed in Chapter 1. If a movement is small and affects a large area, a broad warp may develop, characterized by a slight dip of the bedding. True folds are structures which are bent as a stack of papers is bent when squeezed from the edges. A fold bent upward is an anticline; one bent downward is a syncline. (These correspond to crests and troughs of waves). The sloping sides of folds are the limbs. The plane or surface which symmetrically bisects the limbs of a fold is called the axial plane or axial surface. See Fig. 4-1. If this plane is vertical—the limbs of the fold dipping at equal angles but in opposite directions—

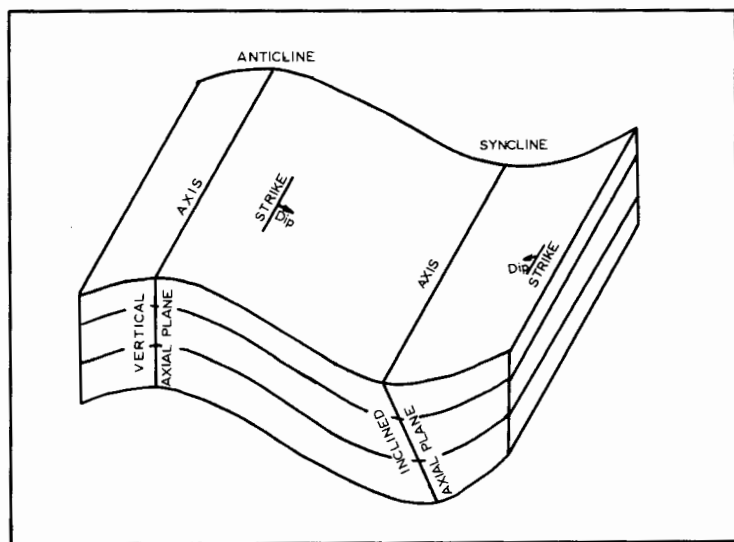


Fig. 4-1 - Components of Folds

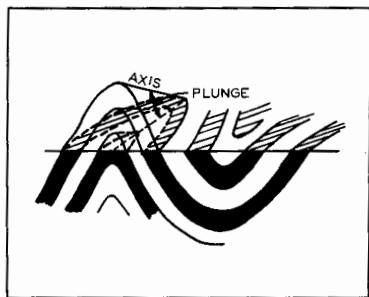


Fig. 4-2. - Plunging Folds

the fold is symmetrical; if the plane is not vertical, the fold is asymmetrical. If both limbs of the fold dip in the same direction but at different angles, the fold is overturned. A recumbent fold is a particular kind of overturned fold in which the axial plane is horizontal or nearly so. If the axial plane and both limbs of the fold dip at the same angle, i.e., if both limbs are parallel, dipping at the same angle and in the same direction, the fold is said to be isoclinal (equal inclination). The axis is the line formed by the intersection of the axial plane and any bedding plane within the folded sequence. See Fig. 4-1. A fold with a non-horizontal axis is a plunging fold. See Fig. 4-2. The trend of the axis is its compass direction; the plunge of the axis is the angle which it makes with the horizontal. See Fig. 4-2.

Closed folds are those in which the limbs have been compressed until they are parallel to each other; further movement results in crushing or flowing of the rocks. Open folds are less intensely folded. A monocline is a fold with only one limb, on both sides of which are horizontal strata, (a local steepening of the beds). A structural terrace is a local flattening of the dip. Very long folds large enough to form conspicuous continental features are described by a prefix from the Greek word *geos* (earth). Thus there are geosynclines and geanticlines. Geosynclines are of especial interest because it is in them that the sediments have accumulated which later were uplifted to form the important mountains of the world. Geosynclines also differ from other folds in that they owe their initial form to a sinking of part of the earth's crust rather than to horizontal compression, although compression invariably follows the deposition of sediment in a geosyncline.

Several types of folds are recognized. Concentric folds are those in which the different beds in the fold all have a common center of curvature. The individual layers in a concentric fold are everywhere about the same thickness. In similar folding the beds all have an equal radius of curvature. The limbs are thinned and the axial regions thickened. In supratenuous folding the limbs are thickened and the axial regions thinned. The radius of curvature increases toward the crest (of an anticline). This type of fold is often the result of compaction of sediments over a buried hill.

Drag folds are minor folds created in weak beds when they are folded between stronger beds.

Domes are closed structures, somewhat like inverted bowls; basins correspond to bowls right side up. A nose is an anticline closed on one end (half of an elongated dome). A synclinorium is a syncline with smaller folds superimposed upon it. Similarly, an anticlinorium is an anticline with superimposed minor folds.

The most intense studies of fold structures in the earth are made in the search for oil. For an oil pool to form there must exist, in addition to the petroleum, a suitable trap. Traps are structures or certain strata which are capable of retaining oil. (These are called, respectively, structural and stratigraphic traps). Structural traps exhibit closure, the vertical distance between the highest point on the structure and the lowest closed contour around the structure. Domes and basins are common closed structures, and plunging folds may be deformed enough to serve as oil traps. Salt plugs are very remarkable structures found in the southern United States oil fields. These plugs are of pure salt which has been taken from deeply buried beds and forced to flow up by the hydrostatic pressure of the overburden. As the plug rose through the sedimentary rocks, its upward motion caused the beds on its borders to be bent upward, forming oil traps at their juncture with the plug. Salt plugs are unknown in Alaska.

Fractures

If the rocks undergoing deformation are brittle or if the deforming pressure is applied to them too rapidly, they may fracture instead of fold.

FAULTS - The best known fractures are faults. A fault is a rock fracture along which movement has occurred parallel to the break. Faults usually are not conspicuous on the surface but are very apparent when encountered in the course of underground work. It is very common to find faults displacing different portions of veins, which themselves usually follow faults.

The same pressure which causes the rocks of a region to crumple into folds may also cause them to fault. The pressure is applied, the rock begins to bend but, instead of taking a permanent fold, the rock suddenly fractures, both sides springing to a position of no stress. When the same pressure continues and the rocks again are flexed (this time to a point just necessary to overcome the friction tending to hold the two sides of the fault together), movement occurs along the fault,

again relieving the stress. The energy released by the sudden movement travels through the earth as earthquake waves.

Faults, like folds, can develop as the result of almost any kind of movement. Faults are classified by the direction of slip and by the angle which they make with the vertical. The two walls of a fault are designated the foot wall, the one underneath; and the hanging wall, that above. Because very few faults are absolutely vertical, almost all faults have a foot wall and a hanging wall.

A fault upon which movement has occurred along the strike is a strike slip fault; one on which the movement has been along the dip is a dip slip fault. If the movement has been neither, it is an oblique slip fault. Rotational movement produces a rotational fault. If the hanging wall has moved down relative to the foot wall, it is a normal fault; if up, is a reverse fault. An oblique slip has a component of dip slip, a component of strike slip, and its net slip, the total amount of movement in the oblique direction. The heave of a fault is the horizontal displacement at right angles to the strike. The throw is the vertical displacement at right angles to the strike. Together, the heave and throw indicate the dip slip but not the strike slip.

The total displacement measured at right angles to the strata on adjacent sides of a fault is the stratigraphic throw, the distance between displaced segments of the same bed. If the strata are horizontal the stratigraphic throw is equal to the throw of the fault. Many of these features are illustrated in Fig. 4-3.

Movement may take place along a fault plane, which is a surface; or along a fault zone which may be several feet thick and be composed of many small faults. Either type may be accompanied by a considerable quantity of gouge, as the mashed, clayey rock product of the movement is called.

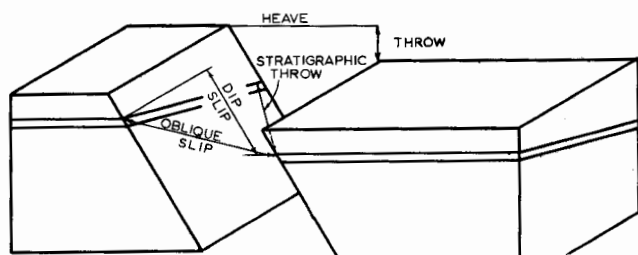


Fig. 4-3. - An Oblique Slip Normal Fault

The wall or cliff left after vertical movement has occurred is called a fault scarp, or escarpment. Frequently, vertical faulting moves a stratum of less resistant rock into contact with a resistant one. The result is faster erosion of the weak one, leaving what appears to be an old fault scarp although it may be some distance from the original fault. Such a feature is a fault line scarp.

The terms and definitions given above are used to describe faults, but are not particular types. The following kinds of faults are recognized as constituting separate geological features. They fall into two broad groups; high angle and low angle types.

High Angle Faults - Several types of High Angle Faults are recognized.

Plateau - These are vertical movements along broad fronts, leaving wide areas as plateaus.

Strike Slip - These are nearly vertical, sometimes very long faults, along which strike slip movement occurs at intervals. The most famous example is the San Andreas, extending for at least 600 miles parallel to the California coast. It is believed that movement (west side north with respect to the east side) has totaled 20 miles. The fault is made up of a half mile wide system of closely spaced fractures. The Southern Alaska earthquake of 1964, of very large magnitude, was caused chiefly by vertical movement along part of a large fault system. It is not known at this time whether there was any appreciable strike slip movement.

Step Faults - High angle dip slip faults sometimes occur closely spaced, forming a series of steps. The blocks between the faults are usually tilted in one direction. This results in a steep fault scarp and a gentle slope back to the next fault. The eastern slope of the Sierra Nevada is a good example.

Gravity Faults - In regions of igneous intrusion or folding, the uplifted rock may later develop high angle faults through subsidence. The subsidence is the result of the igneous intrusions shrinking, or a portion of an intrusion being forced out, or the partial straightening out of

folds after deformation has ceased.

Fault Troughs or Grabens - These are long depressions caused by the uplift of areas on both sides, or by subsidence of a block between two faults or by both processes. Several good examples include 200 miles of the Rhine Valley, the 1000 mile long Bartlett Trough in mid-Atlantic and the series of rifts 4000 miles long from Palestine to southern Africa, containing several rivers and deep lakes.

Keystone Faults - Where two nearly vertical faults are close together, movement on either might cause a settling of the block between them. This may or may not be the cause of fault troughs described above, but Keystone faults do produce depressions bounded on both sides by faults. They are minor features.

Fault Ridges or Horsts - These correspond to fault troughs, except that the block between the faults is elevated rather than depressed.

En Echelon Faults - These are staggered short parallel faults striking at approximately 45° to the trend of the fault zone.

High Angle Thrust Faults Associated with Folds - Thrust faults usually dip at low angles. In some, however, the same pressure which causes the folding develops faults dipping at approximately 45° toward the pressure.

Low Angle Faults

Bedding Faults - These develop on bedding planes and are therefore difficult to recognize.

Low Angle Block Faults - Faulting of the type which produces blocks sometimes occurs at low angles. An example is known of a long block between the Andes and the Pacific, the western fault of which dips west (under the sea) at 6° .

Low Angle Thrust Faults - These are very important in the formation of mountains. When horizontal pressure which tends to create parallel folds becomes greater than the rock is capable of withstanding, nearly horizontal fracture planes develop. Continued pressure thrusts huge blocks bodily along these planes, and may eventually leave them miles from their starting place, unconnected with the rock below. The Alps are the result of extremely complicated thrust faulting. The structure just described, in which the thrust block has overridden, is an overthrust; if it is pushed under, it is an underthrust.

The shapes and movements of faults have been described; the following are ways faults may be recognized in the field. The quickest and most direct way of recognizing a fault is by the actual displacement of some conspicuous bed, dike, or other feature. Fig. 4-4 shows such an obvious fault. Rock surfaces sliding over each other during faulting become polished, grooved, and striated. These surfaces are slickensides. The striations follow the direction of the latest movement. Sometimes the direction of movement of rocks on one side of the fault can be determined by rubbing the fingers along the striations, the surface feels smoother when rubbed in the same direction as the latest movement of the fault wall. Gouge has been mentioned as the finely ground product of abrasion along the fault. When this material is coarser, it is called fault breccia. Sometimes the rock for some distance on either side is modified by the formation of parallel sheets of crushed rock, called the shear zone. Sometimes the rock on either side of the fault has been bent by dragging against the opposite side, an effect called simply drag. When drag can be determined, it gives another indication of relative motion along the fault.

Finally, whenever a contact which is difficult to explain appears between rocks, faulting should be suspected. Such a contact should not be taken as proof, but rather to provide the clue which leads to a search for further evidence.

JOINTS - Joints are breaks in the rock which have opened, without lateral movement, under the influence of tension. Because they sometimes break in a well defined pattern, they may be classified according to mode of origin. Mention has already been made of mudcracks in sedimentary rocks, in which the joints have an original rather than an imposed structural origin.

There are several geologic processes which may put rock under tension. Rock near the surface may be under compression from the rock above. With the removal of the overlying rock by erosion the compression is relieved and the rock may develop sheet jointing parallel to the surface of erosion. The drying out of sediments sometimes forms irregular cracks much larger than mudcracks. The cooling and consequent shrinking of igneous rock cause tension joints to form. In tabular bodies such as sills and dikes these joints form regular columns of polygonal shape, a process called columnar jointing. Daily and seasonal cooling and heating of rock near the surface can produce tension joints. In Alaska, alternate freezing and thawing divide the rock into blocks as the first stage of weathering.

Along the crests of anticlinal folds, wedge shaped tension joints may develop as the result of stretching the strata at the top. Folding produces joint sets in sedimentary rocks, where one set may be parallel to the strike, another parallel to the dip. Any two or more sets form a system. Near the boundaries of intrusions, jointing develops parallel to the flow lines, as well as nearly at right angles to them. Where the flow structure is nearly flat, as at the top of an intrusion, the joints are called lift joints.

Jointing is much used as a guide in quarrying. In fact, without joints, quarrying would be



Fig. 4-4 - A Faulted Coal Seam, Bonfield District. Fault runs diagonally upward from right to left.

very difficult. It should also be remembered that joints, as well as faults, provide the path for the circulation of solutions which deposit mineral veins.

CLEAVAGE- Cleavage is the capacity to break in certain directions more readily than in others. In minerals this is due to crystal orientation. In rock it is due to the regular orientation of certain elongated minerals within the rock (flow cleavage), or of fractures, (fracture cleavage). Although flow cleavage and fracture cleavage form in different ways, they are almost impossible to tell apart in the field.

Flow Cleavage- The cleavage of slates and the less pronounced cleavage of schists is due to differential pressure, which causes new minerals to form that are more stable under stress conditions. The stress causes granulation of the rock and recrystallization into platy or elongated species, such as mica, chlorite, and hornblende. They arrange themselves so as to present their shortest dimensions to the pressure. The flat plates or long dimensions are at right angles to the pressure when the stress is straight compression; but when the stress is such that it tends to rotate the block acted upon, the cleavage is inclined at some angle to the stress. A rock containing oriented minerals tends to split along the mineral planes or through the crystals, producing flow cleavage. The rocks which exhibit flow cleavage are, of course, metamorphic rocks. (See Chapter 3). Most cleavage develops at the same time as folding; the pressure which buckles the earth into parallel folds also causes the mineral formation and the orientation peculiar to flow cleavage. Therefore, it follows that flow cleavage is roughly parallel to the axial plane of the fold in which it occurs.

Fracture Cleavage - Fracture Cleavage consists of very closely spaced fine fractures which do not pervade an entire rock mass as does flow cleavage. In order to form fracture, a rock must be capable of increasing its volume during deformation, thus fracture cleavage is usually found in beds which have slipped along the bedding planes. The cleavage is due not to mineral orientation, but to shearing during deformation.

As already pointed out, fracture cleavage and flow cleavage resemble each other rather closely.

In this chapter the major structural features of the earth's crust have been described. Some of these structures, such as faults, have a direct relationship to mineral veins; others, such as folds, assume great importance in the search for oil. In Chapter 6, some of the relationships between underlying structures and surface forms are discussed.

References

- Billings, Marland P., 1954, *Structural Geology*, 2nd. Ed.: Prentice-Hall, New York
 Nevins, Charles Merrick, 1936, *Principles of Structural Geology*: John Wiley and Sons, New York
 1949, *Principles of Structural Geology*, 4th Ed.: John Wiley and Sons, New York

Chapter 5

HISTORICAL GEOLOGY

INTRODUCTION

Historical geology is the history of the Earth, just as human history is the history of man. Both histories are composed of a sequence of events, but the events in geologic history cover far greater amounts of time. Some of the relatively recent geological events can be dated fairly accurately, and their duration estimated in years. Many happenings, however, especially those of early geologic history stand out only in vague outline, and cannot be dated within millions of years.

The chief reason for the prospector to study historical geology is that at certain times in the earth's history conditions have been favorable for the formation of mineral deposits. (See "metallogenetic epochs", Chapter 7). It is impractical for the prospector to try to work out the history of an area or to try to date the invasion of mineralizing solutions; that is the task of a geologist. The prospector can greatly facilitate his own work by reading publications of the U. S. Geological Survey, the U. S. Bureau of Mines, and the Alaska Division of Mines and Minerals. In order to take advantage of these publications, he should have some knowledge of historical geology.

The age of the earth now appears to be about 4.5 billion years and the age of the oldest rocks about 3.5 billion. What is known of this vast time has been laboriously derived from a study of the rocks formed during that time - their composition, state of alteration, spatial relations to each other, fossil content, and other characteristics. It is necessary to divide the time into shorter intervals, and the rocks which were formed during the intervals into smaller units. This is done according to the following plan:

<u>TIME UNITS</u>	<u>EQUIVALENT TIME-ROCK UNITS</u>	<u>ROCK UNITS</u>
Eon	No equivalent unit	
Era	No equivalent unit	
Period	System	
Epoch	Series	
Age	Stage	
	Zone	
		Group
		Formation
		Member
		Bed

The rocks of the different time-rock units are separated from each other by breaks, representing periods during which there was no deposition, or by changes in environment which caused succeeding rocks to differ from each other even if not separated by a break in deposition. The large breaks, representing long periods during which no new rocks were laid down, and much erosion of the older rocks took place, are used as a basis for separating the longer time units and their equivalent time-rock units from each other. Shorter breaks separate the smaller units. The break in deposition, it is recalled from structural geology, is an unconformity. The time interval during which there was erosion, or nondeposition, or both, is called a hiatus.

The greatest break in the record occurs between eons. Geologic time is divided into the Cryptozoic eon and the Phanerozoic eon. ("Crypto" means "hidden"; "phanero" means "visible"; and "zoe" means "life"). The first period in the phanerozoic eon is the Cambrian; The Cryptozoic eon therefore is called the Precambrian. The hiatus between the two eons is very long, (perhaps longer than all time that has elapsed since the Phanerozoic eon). Most of the rocks of the Precambrian eon are deformed and metamorphosed so that the exact nature of original sedimentary deposits is often obscured. The only reports of life are a few meager impressions of worm tracks and some colonies of microscopic plants. From the Cambrian period on, however, relatively unmetamorphosed rocks, in many places containing abundant fossils, give evidence of the environment during deposition.

The Cryptozoic eon is divided into Early Precambrian or Archeozoic, and Late Precambrian or Proterozoic, eras; the Phanerozoic eon into the Paleozoic, the Mesozoic, and the

Cenozoic eras. ("Paleo" means "ancient", "meso" means "middle", and "ceno", from "kainos", means "recent"). These five eras are separated from each other by major depositional breaks.

The eras of the Precambrian eon have been locally subdivided, but no world-wide system of subdivision has been worked out. The eras of the Phanerozoic eon, however, as shown in Table 5-1 are divided into periods of time corresponding to systems of rocks. Most of the periods are named after the localities where their rocks were first studied, but a few are named on some other basis. The periods were separated by major periods of nondeposition and erosion, which were, however, not so long as those separating the eras.

The periods, with their equivalent systems of rocks, are divided by less widespread breaks into epochs of time and series of rocks. These are divided into ages of time and stages of rocks. No smaller time division exists, but the rocks of a stage may be divided into groups, and groups into formations, the fundamental unit that can be mapped. Formations may be broken down into members, of local occurrence, and members into beds. Groups, formations, members, and beds are rock terms only, and do not indicate any particular time interval.

Formerly it was thought that the major hiatuses separating the eras and the periods from each other were world wide, and that the shorter breaks were regional or local in area. Now it is believed that the gaps, although they exist in Europe where the rock units were first defined, do not necessarily exist everywhere. The concept of time and time-rock units is still valid, even indispensable. It is, however, necessary to recognize that in some parts of the world rocks exist that bridge most, if not all, of the gaps. Such rocks, if no natural break occurs by which to separate them, must be described as belonging to two age groups, e.g., Permo-Triassic.

Diastrophism or crustal movement provides the basis for separating the different time units from each other, because during periods of crustal movement the continents stand relatively higher and deposition of sedimentary rocks is interrupted. These activities occur on a scale widespread enough to provide workable bases for separation. The great movements which periodically buckle the crust are known as disturbances or revolutions, the revolutions being more widespread than the disturbances.

How is it determined to which period a system of rocks belongs, or that a system of rocks in Europe, for example, was formed during the same period as a system in America? Fossils of organisms are preserved in the sedimentary rocks deposited during the time they lived. (Fossils are evidences of former life). Living things constantly change, that is, new species, not too different from other species, appear, and old species become extinct. During a geological period a more or less continuous record of those species which lived during the period is preserved in the sedimentary rocks of the corresponding system. This record need not be continuous at any one place, very likely it is not; but part is represented in one place, and part in another. The older species are in the older rocks, and the later ones in the younger rocks of the series. During the intervals between the periods, the seas recede, and the marine animals must retreat to the continental shelves, where the process of evolution, as the changing of life forms is called, continues. During this time no marine fossils are being deposited in the rocks of the continents, because there are no large inland seas upon the continents. On the continental shelves, however, some of the species which lived in the inland seas during the last period will become extinct, and new ones not in existence during the last period will appear. It is believed that the competition due to crowding on the continental shelves may accelerate the evolution between periods. When the seas again invade the continent, that is, when the next period starts, some of the old forms will be completely missing; this, plus the presence of new forms, will serve to set the new period apart from those before and from those to come. Fossils peculiar to sedimentary rocks deposited during a particular time are called guide or index fossils. Index fossils must have a short time range and a wide geographic range.

Fossils of land organisms are preserved in terrestrial sediments (formed on land). Examples are plant remains in coals and the bones of prehistoric animals found in the mud of Interior Alaska. However, these terrestrial fossils are few and localized compared to those of the seas (marine fossils).

If a rock does not contain fossils upon which its age can be determined, then the position of such rock must be established in relation to another of known age. Every possible clue is used in the age determination of an unfossiliferous rock. An example of such work is the determination of the age of the Birch Creek schist, which is widespread in Interior Alaska. Early workers assigned it to the Precambrian age on the basis of its intense metamorphism. Later workers, realizing that this evidence was not conclusive called it simply "pre-Ordovician", because it had been found in contact with, and beneath, rocks obviously Ordovician in age on the basis of fossils. Later, the Birch Creek schist was found beneath Cambrian rocks, definitely proving it to be Precambrian in age. Then, north of Eagle a group of rocks was found, containing no fossils, but underlying Cambrian rocks. This group of rocks, known as the Tindir group, is very thick and little metamorphosed. It is early Cambrian, or more likely, Precambrian in age. Nearby is the Birch Creek schist, which is severely metamorphosed. Clearly the Tindir group and the Birch Creek schist could not have been in close proximity when the Birch Creek schist was metamor-

phosed, hence it must be much older than the Tindir group. As the Tindir group is known to be Early Cambrian or Precambrian and the Birch Creek schist much older, the Birch Creek schist must be early or middle Precambrian in age.

The process of proving that a rock in one area is of the same age as that in another is called correlation. Some of the methods of correlating unfossiliferous rocks are: by their thickness, degree of metamorphism, position in relation to a bed of known age, or by tracing along continuous outcrops.

The assignment of a rock to a particular geologic age indicates its relative age only. A powerful new method called radioactive dating makes it possible to determine the absolute age of certain igneous rocks with an accuracy which is satisfactory considering the lengths of time involved. Radioactive dating utilizes the fact that radioactive minerals disintegrate at a fixed rate (see radiometric prospecting, Chapter 15). A fresh piece of granitic rock containing uranium or thorium (the average granite contains four grams of uranium per ton of rock) is crushed, and the radioactive mineral extracted. When the igneous rock was first formed, the included radioactive minerals were pure, but in the intervening time a certain proportion has been converted to lead. Accurate chemical analysis determines the ratio of uranium or thorium to lead of radioactive origin, and from a knowledge of the rate of decay, the age of the igneous rock is computed. By this method the ages in years listed in the geologic time chart, Table 5-1, were determined. Radioactive determination of the age of an igneous rock which is in contact with a metamorphic or sedimentary rock of unknown age, often makes possible the age determination of these rocks.

The sedimentary rocks of the world, as was noted in Chapter 3 are of two kinds: marine and terrestrial. Marine sediments are deposited in shallow seas (less than 6000 feet deep) upon the continental shelves. (Sediments deposited in the deep ocean basins have been, with few exceptions, lost to our observation). Terrestrial sediments are deposited on land; in lakes (lacustrine), in streams (fluvatile), by wind (eolian), or by glaciers. The fluvatile sediments may accumulate in a fan or piedmont sloping out from a mountainous area. Generally among water-laid sediments, the fine sediments, limes, muds, and silts, accumulate in bodies of standing water, and the coarser sediments, sand and gravel, in the streams.

It has been noted that only a very few fossils of primitive forms of life have been found in Precambrian rocks, yet at the very least, three fourths of geologic time had elapsed before Cambrian time. This scarcity of Precambrian fossils is thought to be due to the fact that those Precambrian sedimentary rocks that have not been eroded away have been metamorphosed, which process destroys fossils. In addition, it is assumed that the Precambrian organisms had not developed hard parts (shells and skeletons) that could be preserved.

Cambrian fossils, on the other hand, are abundant, and represent a very high degree of evolutionary advancement over the simple Precambrian animal. They could only have evolved during the great hiatus between the Precambrian and the Phanerozoic eons, which testifies that this hiatus was very long, perhaps longer than the time that it has elapsed since.

The geologic ages and outstanding events are listed in the table form (Table 5-1). When reading this chapter it will be helpful to refer to the table. Not all of these ages are represented by the rocks of a particular place. Fig. 5-1 shows Tertiary coal bearing rocks (conglomerate) resting on Precambrian Birch Creek schist. The entire Paleozoic and Mesozoic rock sections are missing. The time represented by the unconformity is perhaps one billion years.

THE CRYPTOZOIC (PRECAMBRIAN) EON

It is difficult to imagine that the Cryptozoic Eon, about which we know very little, represents over 3/4 of the history of the earth. Because the rocks formed during this interval, as might be expected from the length of time involved in their formation, contain many of the world's great ore deposits, they occupy a place of great interest to geologists and prospectors. Each of the continents contains a very large outcrop of these rocks, referred to as a shield. Smaller outcrops, outside of the shields, also occur; among them the Precambrian rocks of Interior Alaska. Presumably Precambrian rocks underlay all continents, but these rocks cannot be seen because four fifths of the world's land area is covered by younger sedimentary rocks. Until about 1885, it was believed that the original igneous crust of the earth outcropped in places, forming the basement, but at that time it was shown that wherever ancient igneous rocks were found (usually metamorphosed) they intruded metamorphosed sedimentary rocks. The conclusion drawn from this observation is that the oldest known rocks at the earth's surface are sedimentary in origin.

Because the Precambrian record is incomplete and obscure, geologists are not in agreement as to how it should be subdivided. A great unconformity separating the rocks of the Precambrian into two divisions is recognized on a world wide scale. For this reason, many geologists divide the Cryptozoic eon into the Archeozoic or Archean era and the Proterozoic or Algonkian era. Other workers, feeling that even this wide division implies a knowledge of Precambrian events which is not justified at present, prefer not to make a division applicable to the entire world. For instance, the U. S. Geological Survey refers to all time before the Cambrian as Precambrian or Proterozoic. The sequences of the Precambrian eon may be worked out locally, but correlations over great distances cannot be made. The U. S. Geological Survey states:

Eon	Era	Period	Epoch	Dominant Processes and Principal Events	Roughly Estimated Time Million Years
PHANEROZOIC	CENOZOIC	Quaternary	Recent	Erosion	
		Tertiary	Pleistocene Pliocene Miocene Oligocene Eocene Paleocene	Glaciation Cascadian Revolution Sedimentation Volcanism	
	MESOZOIC	Cretaceous	Upper	Laramide Revolution	60
			Early	Sedimentation Volcanism Nevadian Disturbance	
		Jurassic	Upper	Sedimentation, Volcanism	
			Middle Early	Palisade Disturbance	
	Triassic	Upper	Sedimentation, Volcanism		
		Middle Early	Appalachian Revolution		
	PALEOZOIC	Permian		Sedimentation, Volcanism	200
		Pennsylvanian		Sedimentation	
		Mississippian		Sedimentation	
		Devonian	Upper	Acadian Disturbance	
			Middle Early	Sedimentation, Volcanism	
		Silurian	Upper	Sedimentation	
			Middle Early	Taconian Disturbance	
Ordovician		Upper	Sedimentation		
		Middle Early			
Cambrian		Late	Sedimentation	400	
	Middle				
	Early	Killarney Revolution	500		
CRYPTOZOIC PRECAMBRIAN	Not Subdivided on world wide basis			Algoman Revolution Sedimentation Some Volcanism	1050
				Laurentian Revolution Sedimentation Volcanism	
					4500

Table 5-1



Fig. 5-1. - Unconformity Representing Perhaps One Billion Years. Precambrian Birch Creek Schist (lower left, light colored) and Tertiary Coal Bearing Formation (upper right, dark colored). Hammer rests on contact. Healy River.

"There is no formal subdivision of time of the Proterozoic; subdivisions of the Precambrian have only local significance." On the following pages the Precambrian rocks in several widely separated areas are described. Although it is possible that rocks in the different localities may have been formed at the same time, the temptation to correlate them must be avoided.

Rocks of Precambrian age are exposed in the lower parts of the Grand Canyon of the Colorado River. The oldest (Vishnu schist), are very strongly metamorphosed and recrystallized schists of sedimentary and igneous origin, with associated igneous intrusions. The base of the rocks is not seen, although the gorge cuts 1/2 mile into them.

Above these rocks lies another series, separated from the Vishnu schist by an unconformity, representing the revolution separating the early Precambrian from the late Precambrian eras. The late Precambrian rocks are not nearly so strongly metamorphosed as the Vishnu schist, showing that the alteration of the Vishnu schist took place prior to the deposition of the late Precambrian rocks. The late Precambrian rocks, the Grand Canyon system, are sedimentary in origin, but contain basic lava flows near the middle.

Precambrian rocks outcrop farther north in the Rocky Mountains; in general the same pattern is recognized: older highly metamorphosed rocks separated from younger, little altered rocks by a widespread unconformity. In the central Rockies the late Precambrian rocks outcrop over a wide range and are called the Beltian series.

Rocks of Precambrian age make up the eastern half of Canada. This outcropping, known as the Canadian Shield, is one of the great shields of the earth. Along the southern edge of the shield near the United States-Canadian border, the rocks have been intensely studied because of their contained mineral wealth.

North and west of Lake Superior are early Precambrian rocks which are assigned to a period called Keewatin. These consist of metamorphosed sedimentary rocks and interfingered volcanics. The iron ores of the Vermilion Range in Minnesota are found in sedimentary rocks of this series. An unconformity of great magnitude separates the rocks of Keewatin age from the overlying rocks of Timiskaming or Knife Lake age. This unconformity represents a period

of orogeny called the Laurentian Revolution. Granites intruded during this orogeny cut the Keewatin rocks but not the Knife Lake rocks.

The rocks of the Knife Lake series consist of metamorphosed sediments and granites. Some of the lowest sediments in the series contain fragments of granites which intrude the underlying Keewatin rocks. These granites are coarse grained, proving that they were intruded under a considerable depth of overlying rocks, which were all eroded away before the granites could furnish sediments for the Knife Lake rocks. This is one more example of the very great amount of the Precambrian record which has been lost by erosion.

Knife lake time was followed by the Algonian Revolution, with great orogeny and intrusion of igneous rocks. This was followed by a long period of erosion during which time most of the earlier formed sedimentary rocks were removed from the Canadian Shield. Many geologists believe that the unconformity representing this erosion separates the Archeozoic from the Proterozoic eras in that area. Certainly it is one of the greatest hiatuses in geologic history.

The next period represented in the rocks of the Lake Superior area is the Huronian. The rocks of this period and that of the next are very much less deformed than the underlying rocks. The rocks deposited early in the period were confined to a great northeast-southwest geosyncline lying in about the present site of Lake Huron. Striated boulders in conglomerate and solidified boulder clay in the middle parts of the Huronian rocks give evidence of the earliest known glaciation. During Huronian time most of the tremendous iron bearing sediments of Minnesota and Michigan were deposited. Huronian rocks also contain much carbonaceous material.

After the deposition of the Huronian rocks, the region was uplifted without much folding or mountain forming, and eroded. The next period, the Keweenawan, was characterized by tremendous lava flows, interspersed with terrestrial sediments (red beds of sandstone and shale). The nickel of Sudbury, Ontario and the copper of Michigan were deposited during the Keweenawan.

In the Great Lakes area the Huronian, and the Precambrian were brought to a close by the Panokean Revolution, during which several mountain ranges were formed. This revolution was world-wide and is often known as the Killarney Revolution. A very long period of erosion followed, removing and destroying much of the Precambrian record.

Farther east, in the St. Lawrence area, early Precambrian rocks are represented by the Grenville series of limestone and other sedimentary rocks. It was intruded by granitic rocks, since metamorphosed to gneiss. These younger Precambrian rocks are called the Laurentian Gneiss.

Alaska - In the foregoing very brief description of some of the Precambrian areas of North America, no attempt was made to correlate the rocks of one area with those of another. In each area there are evidently rocks of different ages, which may or may not be of the same age as rocks in other areas. Similarly, the Precambrian rocks of Alaska are not correlated from region to region.

Earlier in this chapter the evidence was presented in support of a late Precambrian age for the Tindir group north of Eagle, and for an early or middle Precambrian age for the Birch Creek Schist of the Interior. The Birch Creek schist is distributed in the Yukon-Tanana Plateau from Nenana to the Canadian boundary and beyond, and along the northern flank of the Alaska range as far west as Kantishna. Intruded into the Birch Creek of Canada and Eastern Alaska are altered Precambrian granitic rocks called the Pelly Gneiss.

There are other large areas of Alaska, besides those occupied by the Birch Creek schist and the Tindir group, which may contain rocks of Precambrian age. In the early days of geological investigations in Alaska these rocks, contorted schists and gneisses, were all grouped as "Birch Creek schist." Later work showed the need for weeding out from the definitely Precambrian rocks these other rocks. Today they are referred to as "Undifferentiated Paleozoic and older in age." Possibly with more work it will be discovered that some of these rocks are definitely Precambrian in age. The major factor preventing a more accurate age determination at present is the scarcity of Cambrian rocks with which to compare the undifferentiated metamorphosed rocks. As far as is known today, Cambrian rocks outcrop in Alaska only in a small area along the Canadian border north of Eagle.

A large belt of "undifferentiated Paleozoic and older rocks" runs in an east-west direction north of the Yukon from the Seward Peninsula, to the eastern part of the Chandalar River drainage.

In the Cosna-Ruby region there lies another area of these rocks, and the Ketchikan-Wales region also contains them. They are reported in the Canning River region in the Arctic of eastern Alaska.

It appears that during early and late Precambrian time, at least central Alaska was covered by shallow seas in which sediments were deposited. It is possible that these seas were connected with those in which the Precambrian rocks of the Rockies were deposited.

Economic Products - The economic products of the Precambrian eon, besides the iron, copper and nickel of the Lake Superior area already mentioned, include gold and silver deposits in many of the shield areas and uranium and radium at Great Bear Lake.

THE PHANEROZOIC EON

The time which has elapsed since the Precambrian eon ended constitutes much less than one quarter of geologic time. An almost continuous record of fossils and relatively undisturbed sediments have allowed us to learn much more about the Phanerozoic Eon than is known of the Cryptozoic eon.

Paleozoic Era

THE CAMBRIAN PERIOD - The first era in the Phanerozoic eon is the Paleozoic, and the first period is the Cambrian. The period derives its name from Cambria, the Roman name for Wales. During the Cambrian period in North America, two north-south geosynclines, one occupying the present position of the Appalachians, another, the present position of the Rockies, dominated the scene. They are called respectively, the Appalachian and Cordilleran troughs. As these shallow seaways were filled in with the products of erosion, they sank, building up great thicknesses of sedimentary rocks. During the later part of the Cambrian, the troughs were connected by a seaway across the southern part of the continent.

The period is noteworthy for its quiet and stability in North America; no volcanism nor mountain building broke the steady wearing away of the land. Broad warping of the continent took place, however, alternately raising and lowering it below the water. Two major disturbances divide the period into three epochs: lower, middle and upper Cambrian, without, however, producing major unconformities. In Europe, volcanism and uplift occurred during the period.

Alaska - Cambrian rocks in Alaska were laid down in the northern part of the Cordilleran trough in the northeastern corner of Alaska, north of the present Yukon River along the Canadian boundary. Although this is the only locality where they have been identified (limestones, slates, and quartzites of middle to upper Cambrian age) it should be borne in mind that some of the "undifferentiated Paleozoic and older" rocks, already mentioned, may be Cambrian in age.

Economic Products - Few economic products were formed during the period. Certain of the stones, of course, are used in populated areas for building material, and some sedimentary iron ore beds were deposited in Eastern United States.

Climate and Life - In general, the climate was mild. Marine life was abundant; no land animals had yet evolved. Sixty percent of the animals were trilobites, lobster-like creatures, the largest of which was 18 inches long, and the period is sometimes called "the Age of Trilobites." The trilobites provide the guide fossils of the Cambrian epochs.

The period ended with the same quiet that marked its perhaps 70,000,000 years. The land simply emerged for a time, then was submerged; and the sediments of the next period overlies the Cambrian rocks with an erosional gap, but with little angular unconformity.

THE ORDOVICIAN PERIOD - The Ordovician saw the greatest submergence of North America in geologic history. In the East, sand and mud formed sandstone, mudstone, and shale in the Appalachian trough. The western lands were low, consequently little sand or mud was washed into the seas in western and interior North America. All through the Cordillera trough, from Mexico to Alaska, the Ordovician deposits are remarkably uniform limestones, seldom over 300 feet thick.

The period is divided into three epochs. The seas of the first, early Ordovician, in general covered the troughs lately vacated by those of the upper Cambrian. Later they spread north until, in late Ordovician time, only scattered islands remained above water in the interior. The most persistent of these islands are structural domes, which have managed to remain above water during most of geologic time. Today they form areas of old rocks lapped on all sides by younger ones. After the long quiet of the Cambrian, volcanoes were active in the east, spreading ash and lava through the Appalachian trough.

Alaska - The Ordovician period in Alaska is widely represented. Rocks of this age, mainly graywackes, are found on Prince of Wales Island and Kuiu Island in Southeastern Alaska. In the Yukon region, Ordovician rocks are found near Eagle and on the Porcupine River, in the White Mountains north of Fairbanks, and in the Ruby district. They are represented around McGrath in the Kuskokwim, and on Seward Peninsula. Many areas containing rocks which have been classified only as "undifferentiated Paleozoic and older" may be found, with further work, to contain Ordovician rocks.

Economic Products - The economic products of the period are mostly nonmetallic. Oil and gas, as well as building stone, are extracted. Sedimentary iron ores are mined in Newfoundland, but ore deposits connected with igneous bodies are unimportant.

Climate and Life - The climate during the Ordovician period was warm; even in the Arctic the water was warm enough to support corals.

Life in the Ordovician was much like that of the Cambrian, but new species appeared. Primitive fishes, the first vertebrates, appeared during the period. A great shelled animal (cephalopod), with a shell 15 feet long and 10 inches in diameter at its large end, was the largest animal of the period. No land plants or animals are known to have existed.

The period ended with the Taconian disturbance, which raised a "first generation of Appalachians" from New Jersey to Newfoundland. These mountains were worn down in the next period.

THE SILURIAN PERIOD - Silurian history in North America is relatively simple. During the early Silurian, sandstones, conglomerates, and mudstones were deposited in the east. The main seas of the period came in from the Arctic; during middle Silurian times they connected with the Atlantic and Pacific oceans. A small embayment from the north Pacific covered Southeastern Alaska.

This period also is divided by widespread breaks into three epochs; early, middle, and late. The Northern part of the Appalachian region was again the scene of extensive volcanic activity, as evidenced by thick ash and lava layers there.

In North America the period closed quietly, the overlying beds showing in most places no angular unconformity. In Europe, however, the period ended with the Caledonian disturbance, resulting in the rise of the Caledonian Mountains, which traced an arc through Ireland, Scotland, Norway, Spitzbergen, and Greenland.

In early Silurian time, the Appalachian trough received much sandy material, while in the Central and Western seas limestone was deposited. In middle Silurian time, only fine mudstones were being deposited in the east and limestones were still being laid down in Western Canada and parts of Alaska.

Alaska - Silurian rocks are found in Southeastern Alaska, the Yukon region, the Kuskokwim Region, Seward Peninsula, Northern Alaska and Northwestern Alaska.

In southeastern Alaska three main areas of Silurian rocks are known, with minor outcrops between them. These are Dall Island and adjacent territory, the Northern part of Prince of Wales Island, and the Glacier Bay area. The rocks consist of graywacke, conglomerated, shales and limestones with interbedded thick lava beds.

In the Yukon they are found along the Canadian border and Porcupine River, and from the White Mountains to the Hot Springs District. They are also found in the Ruby-McGrath area, and they crop out in a band along the south slope of the Brooks Range, from the Canadian border to the Arctic Ocean, and on the Seward Peninsula.

Economic Products - Late Silurian times saw deserts in the east; salt and gypsum were precipitated from the dead seas trapped in the deserts. The salt deposits are extensively mined in New York and adjacent states. Again no metalliferous mineral deposits of igneous origin were formed. Important iron ores of sedimentary origin were laid down over a wide area, from New York to Alabama. These are called the Clinton iron ores, and occur as beds in mudstone.

Climate and Life - The climate in North America was warm again, at least during part of the period.

From the point of view of life, the period is important in that the first primitive land plants appeared. The trilobites were still extensive, but declining; fish were increasing but of minor importance. Certain scorpions lived, but whether they were air breathing or aquatic is not known.

THE DEVONIAN PERIOD - The period is divided into three epochs; early, middle, and late Devonian. Lower Devonian rocks were deposited in the Appalachian trough; no lower Devonian rocks are found farther west, except for Southeastern Alaska, which was occupied by a small embayment of the Pacific. During middle Devonian times, the northern part of the Appalachian trough was raised above sea level and folded into mountains. This orogenic movement is called the Acadian disturbance. The Cordilleran trough became filled with water, and connected with the Arctic and southern Appalachian waters. The western and eastern parts of the continent were continually submerged, while the central part was very shallow and sometimes emergent. Toward the close of the period the Appalachian trough was above water. Volcanic activity attended the Acadian disturbance. Lower Devonian rocks in the East are fine grained; limestones and minor amounts of mudstones are the chief rocks, with a clean sandy layer derived from the sandy mantle of the Silurian rocks. As the Acadian disturbance progressed, muds and sands were deposited. In the western part of the continent the rocks are highly calcareous.

Igneous activity and mountain building movements were world-wide during the Devonian. In Europe, North America and Australia, igneous rocks were intruded and extruded, and mountains were raised. There is evidence that a land bridge from Ireland through Iceland to Newfoundland existed at that time.

Alaska - In Alaska, the Devonian rocks are widespread except along the Gulf of Alaska. Rocks of early Devonian age, however, have not been found anywhere in the state, which has led to the belief that this may have been a time of extensive mountain building in Alaska.

In southeastern Alaska the Devonian rocks are numerous in the southern half of the region. They consist of detrital (mechanically eroded) sediments, much volcanic lava and tuff, and little limestone. Devonian rocks extend across the northern portion of the Yukon-Tanana Plateau, from the Mantley district to the Canadian border. They also crop out along the south slope and the crest of the Brooks Range. Rocks of probably Devonian age crop out along the northern flank of the Alaska Range west of the Nenana River, and also farther east, around the Tok and Chisana Rivers.

Economic Products - The economic products of Devonian period are chiefly oil and gas and

black phosphates.

Climate and Life - The evidence indicates a mild climate for the Devonian period. The Devonian is called "the age of fishes," because fishes were the dominant form of life during the period. Great progress in the evolution of the vertebrates took place during the Devonian, and two common groups of "lung" fishes had their swim bladders attached to their throats so that they could exhale and inhale at will. These were rudimentary lungs. Before the end of the period certain fish emerged onto the land, and the first amphibians had evolved.

The period ended with the elevation of mountains in the east by the culmination of the Acadian disturbance. From New England north, the sedimentary rocks of the Appalachian geosyncline also were raised into mountains, but most of the geosyncline was a sloping plain, built up from outwash from the mountains farther east.

THE MISSISSIPPIAN PERIOD - There are three more periods in the Paleozoic era, the Mississippian, the Pennsylvanian, and the Permian. Early in the study of geology, when it was thought that coal was restricted to certain great coal-bearing rocks of Europe, these rocks were named Carboniferous. The use of this name was expanded until it included the limestones and mudstones below the coal bearing rocks. The terms lower Carboniferous and upper Carboniferous were then adapted to separate the lower, less coal-productive beds from the upper. When American rocks began to be studied, these names were changed to the Mississippian and the Pennsylvanian. European geologists favor considering the Carboniferous as a period, dividing it into lower and upper carboniferous Pennsylvanian epochs. American preference, which is followed in this book, considers them separate periods.

It was noted that at the end of the Devonian the Appalachian trough was uplifted to an alluvial plain. Submergence during the Mississippian period began farther west, in the Mississippi Valley region. The Appalachian trough continued to subside throughout the period, but since it constantly received sediments from mountains to the east, it remained above sea level, and the sediments there are mainly terrestrial. The coarse sediments were caught in the Appalachian trough; in the West the rocks are predominantly limestones. The pattern in the West during the earlier parts of the period was much like that of the Devonian period, with a seaway extending to the Arctic through the Cordilleran trough. Later this seaway was cut off, and a connection between the Pacific and the Atlantic through the southern states was opened. Late Mississippian time was marked by widespread mountain building in Colorado, Appalachia, and Llanoria (an ancient landmass about where the Gulf Coast is now). This mountain building was to continue throughout the rest of Paleozoic time, culminating in the Appalachian revolution at the end of the era. In Europe, several ranges, called the "Variscan", were uplifted during the period.

Alaska - In Alaska, the Mississippian is well represented, except in the southwest. In southeastern Alaska conglomerates and calcareous sandstones outcrop along the Chitina River and in the Nutzotin Mountains in the Copper River region.

In the Yukon River region, Mississippian rocks occur in the Chisana district, along the upper Yukon River, in the Tolovana District (Livengood chert), around Rampart, on the Porcupine River, and the Chandalar and Koyukuk districts. An occurrence of interest near Nation contains bituminous coal. Mississippian limestones and mudstones form a belt along the northern slope of the Brooks Range and have also been found on Seward Peninsula.

Economic Products - Oil, gas, and coal are produced in great quantity from Mississippian rocks.

Climate and Life - The climate during the Mississippian period showed wide variation. Arctic Alaska has Mississippian fossils of coral while in Australia, tillite has been found, showing that glaciers existed there. The humidity also varied from place to place and changed greatly with time. In some localities in Pennsylvania, the presence of coal and other organic matter indicates a humid plain, while later rocks indicate semi-arid and desert conditions.

During the Mississippian period the corals and trilobites declined still further, while the fishes were abundant though less varied than during the Devonian. The best known fishes of the period are the shell crushing sharks. Footprints of amphibious land animals are preserved, as well as the crushed remains of land plants.

THE PENNSYLVANIAN PERIOD - At the beginning of this period the central states were a lowland bordered on the south and east by mountains. The subsidence spread waters from the West into the southern part of the Cordilleran trough, and across the southern and central states to Pennsylvania. The Appalachian trough had been above sea level since Devonian time, but fluctuations in sea level now alternately brought shallow seas, and as detritus accumulated, caused swamps to form. The same holds true for the mid-continent area. Throughout the period, however, certain positive (above sea level) areas were rising continuously, and new mountains were rising out of the sea. One of these was in the maritime provinces of Canada (Acadia), another in Oklahoma and Arkansas (Llanoria), in Colorado, and at the close of the period, the Marathon Mountains in Western Texas. The period closed with the Marathon disturbance and a general uplift of the mid-continent area, which crowded the seas toward the west. In Europe and Asia great mountain building occurred at the end of the period.

The great coal deposits of the Pennsylvanian rocks were formed in extensive swamps. Formerly

the Pennsylvanian coal seams covered much wider areas in North America; now coal is found only in the synclinal basins where it has been protected from erosion. The principal areas of coal are named from the localities in which they occur, e.g. the Appalachian field. Intercalated with the coal in most of the fields are sandstones, mudstones, and limestones, showing the alternation from active deposition of detritus, to swampy conditions, to shallow seas, followed by uplift and renewal of the deposition cycle.

Alaska - In Alaska, Pennsylvanian rocks are much less widespread than are Mississippian. Fossiliferous limestone has been tentatively identified as Pennsylvanian on the west coast of Prince of Wales Island in Southeastern Alaska. There is some evidence that the bituminous coal-bearing formation near Nation, mentioned as of Mississippian age, is actually Pennsylvanian. Although Pennsylvanian rocks have not been identified positively elsewhere in Alaska, they may occur with other Carboniferous rocks which are widespread. Evidently Alaska stood above sea level during much of Pennsylvanian time.

Economic Products - The chief economic product of the period is, of course, coal. Oil and gas are also found in quantity in rocks of this age.

Climate and Life - The evidence shows the climate during the Pennsylvanian period in general was warm. Corals of that age are found in Spitzbergen; the foliage of the swamps in which the coal was produced is of tropical varieties. The climate also must have been quite humid.

The most noteworthy life, and from the standpoint of man, the most important of the period were the swamp forests which formed the coal. The trees, though big, were not of the types found today, but were mostly soft-tissued, sporebearing plants. Insects, some of them over a foot long (the largest in geologic history), and amphibians were the most common land animals. A few small reptiles made their appearance during the period.

THE PERMIAN PERIOD AND THE END OF THE PALEOZOIC ERA - The unrest which started in the Mississippian and continued through the Pennsylvanian, reached a climax at the end of the Permian which was one of the great revolutions of the earth.

In eastern North America the transition from Pennsylvanian to Permian was gradual. The Appalachian trough was still a flat plateau, upon which deposition continued during the early part of the period. Toward the middle of the period the trough was further uplifted, and erosional material from the East was carried to the mid-continent basin, which was still connected with the Atlantic, and through the Gulf of Mexico, to the Pacific. As the continent continued to rise, the mid-continent basin became smaller and smaller, and at the same time the climate became arid. The result was a vast dead sea, and eventually the deposition of great deposits of salt, gypsum and anhydrite with limestone. During early Permian time much of Alaska and the Canadian Arctic was covered by shallow seas. The Appalachian geosyncline, which had existed all through the paleozoic, became a mountain range which still exists today. Another small range (the Ouachita Mountains) was formed in Arkansas and Oklahoma during the period. Volcanoes burst out along the west coast from Mexico to Alaska, the first such activity in the West during the whole era. This crustal unrest was evident in Europe also; the Urals were formed at this time and bear a close resemblance to the Appalachians.

The Permian deposits in North America are found mainly in the mid-continent area and the southern part of the Cordilleran region, where they are interbedded with volcanics. One of the world's greatest salt deposits was formed in the mid-continent basin during the period. This area is sometimes referred to as the Permian basin.

Alaska - In Alaska, rocks formed during the Permian are fairly common, but not so widespread as those of the Mississippian. In southeastern Alaska limestones and cherts are found, chiefly in the Kupreanof area. In the Copper River region some of the limestones and some of the lava flows of the Nicolai greenstones (of economic interest because of their copper content) are Permian. Limestone of probable Permian age is known in the Cook Inlet region.

Permian and Carboniferous rocks are found around Nation on the Yukon River, along the Porcupine River, and in the Eastern Chandalar district. In northern Alaska, Permian sandstones are definitely identified in the Canning River district. Limestones and volcanics have been found in the Akiak district, and Permian limestone crops out near Goodnews Bay, both in the Kuskokwim region. Limestone overlain by volcanic rocks, both of Permian age, occurs in the Tikchik area in the Bristol Bay region.

Economic Products - Most of the economic products formed during the Paleozoic era are sedimentary in origin. During the Permian and during the interval before the beginning of the next period, however, extensive igneous activity resulted in metallization in several continents. (North America was excepted). Among the deposits formed at that time are the tin lodes of Cornwall and Saxony, the pyritic deposits of Rio Tinto, Spain, and the platinum of the Urals. Others are the tin, tungsten, gold and bismuth of Australia, the gold-silver of France, Germany, and Spain, and base metal lodes in Russia, China, Japan, Burma, and Malaya.

Climate and Life - The climate in Permian times showed the extremes that any period of extensive mountain building and emergent continents exhibit. As already noted, desert conditions existed in some parts of the world during the period. Lofty mountain ranges lying across the direction of prevailing winds caused an unequal distribution of rainfall. The large land masses restricted the flow of ocean currents, causing an unequal distribution of heat over the

earth. The outstanding evidence of climatic extremes, however, is the glacial tillite found in many parts of the world. In the southern hemisphere glaciation was widespread, even in the tropics, but in the northern hemisphere only India was much affected. Striated boulders in the Permian rocks of Alaska have been found, but their glacial origin has not been proved.

Rapid evolution of the plants took place during the period as the cold weather greatly stimulated the development of hardy forms. The soft-tissued trees of the Pennsylvanian forests either declined sharply or became extinct altogether, and the conifer first appeared in the Permian. The Permian was a time of great specialization and change among the animals also. Many species of reptiles appeared, although none of them over 8 to 10 feet in length. Some of these have characteristics which show them to be the forerunners of the mammals.

The Mesozoic Era

Although by far most of geologic time had gone by before the advent of the Mesozoic Era, life was just entering what may be called its middle age; hence the name meso (middle) zoic (life).

The Mesozoic has been called the age of reptiles. On land, in the air, and in the sea, lived an assemblage of reptiles of all descriptions, from tiny animals the size of rats to monstrous creatures 80 feet long.

THE TRIASSIC PERIOD - The Appalachian revolution elevated the entire eastern half of North America above sea level. During the first half of the Triassic, the mountains were worn down. During the second half of the period large scale faulting occurred along the axis of the Appalachian range, forming a narrow chain of block mountains, analogous to the Sierra Nevada of the present day. Erosional detritus was swept by streams into the troughs formed by faulting, and as the troughs sank steadily, great thicknesses of terrestrial sediments accumulated. Interbedded with the sediments are several lava flows.

In the Cordilleran region extensive terrestrial red and maroon deposits were laid down under arid conditions. Marine sediments interfinger with the continental deposits in the West indicating fluctuation of the sea level during Triassic times. Farther west marine sediments were deposited in what is called the Pacific Coast geosyncline, parallel to the present coast from California to Alaska. Mostly limestones and shales were formed, and at different places, especially in Canada, very large lava flows are interbedded with them.

Alaska - In Alaska, the earlier half of the Triassic system is missing (a hiatus exists) indicating a very long period of erosion. In Southeastern Alaska the system is represented by two units separated by an unconformity. The rocks consist of conglomerate, sandstone, and limestone, with considerable black slate. The rocks, wherever exposed, are strongly deformed, although not so strongly as those of Paleozoic Age. In the Copper River region the rocks containing the copper deposits are part of Triassic age. In the Cook Inlet-Susitna, and Bristol Bay regions, several localities contain Triassic rocks; from the headwaters of the Susitna almost to Dillingham, occur limestones, shales, and cherts also of Triassic age.

Triassic rocks are scarce in the Yukon River region. Shales of this age are known in the White River, and Triassic fossils have been reported from the Sheenjek district. Shales and shaly limestones have been found near Nation. The shale is of interest because its bituminous content makes it a good grade of oil shale. (This, of course, does not mean that it is economically exploitable at present).

In Northern Alaska and the Brooks Range, Triassic rocks are found in east-west belts from the Canadian boundary to the Arctic Ocean. They include mudstones, limestones, sandstones, and cherts, and are strongly folded and deformed.

Economic Products - The economic products of the period include red and brown sandstones (red beds) used for building stone; coal in Australia, Europe and Asia, salt and gypsum.

Climate and Life - The climate of Triassic time was much warmer than that of Permian time, as evidenced by the lack of glaciation and the spread of corals to the north. Because of the emergent continents, great arid regions also existed. The climate showed greater extremes than some of the Paleozoic periods of great submergence; Triassic corals are not found in the high Arctic regions. The widespread occurrence of reptiles indicates a warm climate, since reptiles cannot endure freezing.

Remains of plant life of the Triassic are relatively scarce, a fact which may reflect unfavorable climate, but probably is caused by the poor preserving qualities of terrestrial red beds. In the petrified forests of Arizona fossilized logs of conifers as much as ten feet in diameter are found. The soft-tissued trees had almost vanished by Triassic time.

Among the animals, the reptiles had by this time dominated the land, although the largest was only about 25 feet long. The dinosaurs (Greek *deinos*, terrible + *sauros*, lizard) appeared during the period. They quickly outnumbered all other reptiles, partly because their legs were under their bodies instead of on their sides, enabling them to walk rather than crawl. Two groups of reptiles returned to the sea, and before the period ended the first primitive mammals had appeared.

THE JURASSIC PERIOD - As it was during the Triassic period, the eastern half of the

continent was above water for the entire Jurassic. Unlike the Triassic period, however, the Jurassic produced no rocks in eastern North America. It is likely that the Appalachian region was depauperated during the period.

In the West, a new geosyncline began to form over the present site of the Rockies, called for this reason, the Rocky Mountain geosyncline. The sea invaded this trough from the north and from the south, leaving dry land between them in which desert deposits accumulated during the period. The Pacific Coast geosyncline persisted throughout the Jurassic period and received a great thickness of detrital sediments and volcanic material.

The northern part of the Rocky Mountain geosyncline contained a body of water called the Sundance Sea. At the southern end of this sea, shallow land-locked lagoons developed, from which gypsum precipitated, interbedded with terrestrial deposits. After the retreat of the sea, the basin was filled with mud and sand. This formed the Morrison formation, and in it are preserved the most spectacular dinosaur bones found on the continent. The shallow water marine sediments of the Sundance Sea are known as the Sundance formation, and form a thin layer between the red beds of the Triassic and the overlying terrestrial sediments of the Morrison formation.

Between the Rocky Mountain geosyncline and the Pacific Coast geosyncline, a positive narrow area persisted, which supplied sediments to both troughs. The southern part of the Rocky Mountain geosyncline was occupied by a sea which connected to the Atlantic across Mexico. Toward the end of the period, in western North America, strong orogeny set in, crumpling the Pacific Coast geosyncline and forming long ranges of fold mountains. This, the most intense deformation in the West since Precambrian times, is called the Nevadan disturbance. Preceding and accompanying this disturbance was tremendous volcanic activity all the way from California to Cook Inlet. Repeated intrusions built up batholiths, the longest of which is the coast range batholith of Canada, 1100 miles long. Very important mineralization accompanied this volcanism. The Nevadan disturbance was a sub-climax in an orogeny that continued through the next period (The Cretaceous), to culminate farther east in the Laramide Revolution at the end of the Cretaceous and die out in the following period.

Alaska - The most complete sequence of Jurassic rocks in North America is found in Alaska. They are confined mostly to the coast areas from Southeastern to the Alaska Peninsula, in the Copper River, and in Northern Alaska. No sedimentary Jurassic Rocks are known in the Yukon River region except for a small area near the headwaters of the Tanana. They are found north of the Brooks Range.

In Southeastern Alaska, Jurassic rocks are divided into two groups, the older consisting of flows, tuffs, slate, and graywacke, and the younger, mudstone, graywacke, and conglomerate. Intrusive rocks of Jurassic age occur with them (the Coast Range batholith intruded during the Nevadan orogeny, extends the length of the area).

Jurassic rocks are also found in the Copper River Region and on the Upper Tanana. In the Cook Inlet, Susitna-Kenai, and Alaska Peninsula Regions, Jurassic lavas are overlain by Jurassic sediments. The oldest of the sediments is the Tuxedni sandstone (which contains oil seeps). Most of the formations found along Cook Inlet are also found in the Matanuska area.

Jurassic rocks also occur in the area occupied by the Skwentna and Yentna Rivers and probably in the Valdez Creek district and around Broad Pass.

Rocks which correlate with those of the Cook Inlet region are found all along the Alaska Peninsula, as far west as Herendeen Bay. Jurassic rocks probably occur on Kodiak Island.

In northern Alaska Jurassic shales and sandstones with burned coal beds occur in the Canning River, and Jurassic rocks are also found in the Firth River drainage.

The Jurassic saw some of the greatest intrusive activity in North America, and Alaska received its full share of this activity. The Yukon River region, although it contains almost no sedimentary Jurassic rocks, was host to innumerable intrusives of great importance as mineralizers in Alaska. Almost every region in Alaska contains metallic mineral associated with intrusives of Jurassic or other Mesozoic Age.

Economic Products - The great intrusions of the period, and mineralization associated with them, are widespread in the western part of the continent from Mexico to Alaska.

Jurassic coal is important in various parts of Europe (the most important is at Spitzbergen), and in Siberia and other parts of Asia, in Australia, and on Tasmania. In North America, the only workable Jurassic coal is in Greenland. Some oolitic (sedimentary) iron ores were deposited in Europe.

Climate and Life - The climate in Jurassic times was, in general, warm as is shown by the coal found in different parts of the world, range of reptiles, corals, and other life peculiar to warm climates. The life of the Jurassic, as would be expected, was dominated by the reptiles. Throughout the period innumerable species flourished; dinosaurs up to 80 feet in length existed.

The first bird evolved from the reptiles during this period, and small mammals developed rapidly. The plants were much like those of the Triassic period. Great forests of conifers were similar to our modern plants, while cycads (types of palm), were widespread. The deciduous (hardwood) trees had not yet appeared.

THE CRETACEOUS PERIOD AND THE END OF THE MESOZOIC ERA - The Cretaceous

(Latin, creta: chalk) was named after the chalk cliffs of the English Channel coast. Chalk occurs in large amounts only in Cretaceous rocks.

The last extensive submergence (and also one of the greatest) of North America occurred during the Cretaceous. At its peak about the middle of the period, 50 per cent of the continent was under water. The Rocky Mountain trough, first formed during Jurassic times, became submerged again under the seas encroaching from the Arctic and the Gulf of Mexico. This submergence was much greater than previously, covering an area nearly 1000 miles wide, from Idaho almost to Wisconsin. During the last part of the period the area gradually emerged leaving a swampy lowland, in which plant remains and terrestrial sediments accumulated. The Rocky Mountain regions from Mexico to Alberta contain vast deposits of Cretaceous coal. On the Pacific Coast the ocean lapped against the ridge or geanticline that separated the Rocky Mountain Geosyncline from the Pacific Coast Geosyncline. This ridge, called the Mesocordilleran Ridge, continued to rise depositing sediments both east and west and dispersing ash and lava from its numerous volcanoes.

The closing stages of the period were marked by unrest which culminated in one of the greatest revolutions in earth history, the Laramide Revolution during which the Rocky Mountains were formed. Great compressive forces formed arches running north-south, with synclinal basins between them. These mountains occupy a position in the West similar to the Appalachians in the East. Each was the product of an orogeny which closed an era, and each was formed from the accumulated sediments in a major trough. The Appalachians were formed from the Appalachian trough at the end of the Paleozoic era, and the Rockies were formed from the Rocky Mountain geosyncline at the end of the Mesozoic era. Volcanoes were active all along the range as it was rising. The Andes of South America were formed at this time. As noted previously, this Laramide Revolution, which raised the Rocky Mountains, was a climax to a period of unrest that began in the Jurassic period, and continued into the Tertiary.

In the Atlantic coastal region the Cretaceous rocks are represented by poorly consolidated sandstones and clays. The eastern part of the continent at that time was relatively low, and this, coupled with the small amount of down-sinking of the coastal plain, resulted in only thin layers of Cretaceous rocks in the region.

In the Gulf Coast region, sediments laid down in the Gulf, which at that time extended 600 miles farther north than at present, consist of sands and muds in the north, muds farther south and east, and limestones in the east, around Florida. This is the distribution of sediments that would be expected from streams occupying the area where the present Mississippi system exists today. These Cretaceous rocks are much thicker than on the Atlantic Coast.

In the western Gulf and the Cordilleran regions which cover most of the Great Plains and Rocky Mountains from Mexico to Alaska, marine and terrestrial deposits are well represented. The lower Cretaceous rocks are more limited in distribution than those of upper Cretaceous, which underlie most of the Great Plains and the Rockies. The best known of these upper Cretaceous formations are the following: The Dakota Sandstone, 100 to 400 feet thick composed of stream deposits, very persistently underlies the plains. It is a great artesian water supplier. The Colorado group consists of dark mudstones and chalky limestone, which contain many marine vertebrate fossils. Above this, the Montana group consists of a thick marine shale, the Pierre Shale, and the overlying marine Fox Hills sandstone. The Laramie group, above the Montana group, is composed of several thousand feet of non-marine coarse sediments laid down in the geosyncline after the sea had withdrawn. It thins toward the east, and contains many fossil dinosaurs and land plants.

On the west side of the Mesocordilleran ridge are thick marine and terrestrial deposits extending from California to Alaska. Great amounts of igneous rock were intruded during the Cretaceous, accompanying the Laramide Revolution. Several large batholiths were formed.

Alaska - At the beginning of Cretaceous time, Alaska, was worn down to low relief, and at one time or another during the period almost all of it was submerged, although not necessarily all parts at once. Cretaceous rocks, therefore, are widely distributed. The boundary between Jurassic and Cretaceous rocks is obscure in most parts of Alaska. In Southeastern Alaska rocks of probable early Cretaceous age occur in several localities. No rocks of late Cretaceous age have been found in Southeastern Alaska, indicating that there was uplift and active erosion during the last part of Cretaceous time. Intrusion of part of the Coast Range batholith was probably going on at this time, which might account for the continued uplift.

In the Copper River region, Cretaceous rocks appear in the Chitina valley, and rocks of Cretaceous age occur in the Matanuska Valley. Strongly deformed Cretaceous sedimentary rocks extend from the southernmost tip of the Kenai Peninsula northeastward into the Copper River region.

Cretaceous coal of lignite to bituminous rank has been mined around Herendeen Bay and Chignik since before the turn of the Century.

In the Kuskokwim River Region, Cretaceous rocks out-crop over large areas, the largest extending northeast from Aniak to the headwaters of the Nowitna, including the mining camps of Iditarod and Ophir. Since the Iditarod and Nowitna lie in the Yukon River basin, this out-crop extends beyond the drainage of the Kuskokwim. Rocks of Mesozoic age which may be

Cretaceous occur at several localities, among them near Goodnews Bay and around Bethel.

In the Yukon River region seven general areas of Cretaceous rocks are recognized (1) the Marshal area of the lower river, (2) the Nulato area, (3) the Iditarod-Nowitna area already mentioned, (4) an area extending northward from near Ruby into the Upper Koyukuk, (5) the Rampart Hot Springs area, (6) an area in the vicinity of the Yukon and the International boundary, and (7) the Cantwell formation of the Bonfield and Kantishna districts along the north flank of the Alaska Range. The rocks consist of conglomerates, sandstones, mudstones, and limestones. The large area of Cretaceous rocks outcropping on the lower Yukon extends northward and covers the eastern part of the Seward Peninsula. Some of the areas of Cretaceous rocks in the Yukon district extend northward into the Selawik, Kobuk, and Noatak valleys of northwestern Alaska. The greatest area of Cretaceous rocks in Alaska, however, occurs in Northern Alaska, where an east-west strip over 350 miles long is recognized from the Canadian border to the Arctic Ocean on the west, and occupies most of the area between the Brooks Range and the northern coast. The rocks are mostly sandstones, with subordinate amounts of mudstone and conglomerate. They were laid down in shallow water and have suffered deformation during uplift of the Brooks Range. They are known to contain coal, gas, and oil. Intrusive rocks of Cretaceous age, along with those of earlier Mesozoic periods, are widespread in Alaska. They are believed to be the source of much of the metallic mineralization of Alaska.

Economic Products - The economic products of the Cretaceous are numerous and varied. Coal of Cretaceous age is mined in the Rocky Mountain area from New Mexico to Alaska. This area contains tremendous reserves of lignite and bituminous coal. Petroleum occurs in Cretaceous rocks in many parts of the world, notably in the Gulf area, Mexico, and the Rocky Mountain region. As mentioned before, Cretaceous rocks are a great source of water in the plains.

Widespread metallization accompanied the Cretaceous intrusions in the West. The copper-zinc veins of Butte, Montana, were probably formed at this time, as well as many of the California deposits. It is likely that most of the metalliferous deposits of Alaska are associated with Jurassic Cretaceous intrusions.

Climate and Life - The climate during the early part of the Cretaceous was cooler than during the Jurassic, as evidenced by the restriction of corals to lower latitudes, and the existence of glaciers in Australia. Later in the period, however, the climate warmed.

Life in the Cretaceous took on a modern aspect. Deciduous trees appeared and dominated the continents. These trees belong to the Angiosperms, the highest form of plant life, which includes the flowering plants and provides almost all of the plant food of the earth. Until the evolution of these plants, the great expansion of the mammals was impossible. The evolution of the reptiles reached its culmination during the Cretaceous period. Among the dinosaurs was the mighty *Tyrannosaurus Rex*, the largest flesh eater of all time, which spanned 45 feet from nose to tail. Other dinosaurs were only two feet high, with all sizes of carnivorous and herbivorous species between. Among the marine reptiles, a new tribe appeared: the mosasaurs, the largest of which reached 35 feet in length. The flying reptiles were less varied and numerous than before, but larger and more specialized. One pterodactyl had a wingspread of 25 feet. Birds were evolving rapidly; one diving bird had specialized to the point where its wings were useless for flying.

The mammals were still insignificant, small pouch-bearing species and insect eaters, although they held their own and managed to increase during the period. As at the end of the Paleozoic era, many species became extinct in the interval between the end of the Cretaceous period and the beginning of the Cenozoic era. Because the animals were larger and more modern, however, the events seem more awe-inspiring, taking on somewhat the aspects of a catastrophe. Not one dinosaur lived into the Cenozoic, nor one flying reptile, while among the marine reptiles only the turtles survived. Even among the invertebrates, a number became extinct. The death of so many races of such diversity has led to the period being called the "time of great dying".

It is probable that no one cause is responsible for this extraordinary change. Possible causes are great reduction in the continental seas, the rise of mountains all along the west coast of the Americas, the vanishing of the large swampy areas, the cooling temperature, and the rise of plants more favorable to mammals than to reptiles.

The Cenozoic Era

About 60 million years have elapsed since the opening of the Cenozoic era, which makes it by far the shortest era, but it must be remembered that it is just at its beginning. Different geologists use different systems of subdivision, one of which considers that the Cenozoic era is so far composed of only one period, also called the Cenozoic, which is still going on. Another considers that the era is divided into the Tertiary period, which covers the time up to the advent of glaciation, and the Quaternary period, covering the time which has elapsed since then (about one million years).

The origin of the words "Tertiary" and "Quaternary" is interesting. When the rocks of Europe were first studied, it was recognized that (1) an igneous core existed, surrounded on the flanks by (2) consolidated sedimentary deposits, and that on the plains beyond were (3)

poorly consolidated gravels and sands, and that much of the low country was covered by (4) unconsolidated material (drift) considered to have been left by the Biblical flood. These were called primary, secondary, tertiary, and quaternary. Of course, such a classification could not hold up long, for the igneous core of a mountain may actually be younger than its sedimentary flanks. The terms tertiary and quaternary remain in use, however, as a vestige of that day, and they probably always will. The U. S. Geological Survey uses these terms, so it is desirable for the prospector to be familiar with them, especially when dealing with placer geology. On the other hand, some authorities do not consider the Tertiary and Quaternary to be separate periods.

THE TERTIARY PERIOD - The period is divided into five epochs, called from earliest to latest, Paleocene (ancient recent), Eocene (dawn recent), Oligocene (little recent), Miocene (less recent), and Pliocene (more recent).

Since the Mesozoic, no more than ten per cent, and an average of three per cent, of the present continent has been covered by continental seas. Most of the Cenozoic record, therefore, lies in its terrestrial deposits. During the era the face of the earth has taken the shape seen today. A noteworthy characteristic of sedimentary rocks of Cenozoic age is their poor consolidation. Some hard tough rocks are found, of course, but as a general rule they are soft, crumbly, and easily eroded. This quality of easy erosion sometimes results in the development of bad lands topography.

In the East the Atlantic overlapped the present coast from New Jersey to Mexico and extended up the Mississippi Valley over 600 miles. Great thicknesses of Tertiary rocks are found under Louisiana, and drilling indicates a geosyncline with its axis parallel to the coast of Louisiana and Mississippi. Early in the Tertiary the Appalachians were peneplaned, then arched up to about 4000 feet; erosion has since carved their present shape. The central part of the continent, constituting the plains area, has had an uninterrupted history of quiet erosion, giving it its present low relief.

The Laramide Revolution left the Rockies rugged and elevated. During the Tertiary period they were worn down, and the products of their erosion filled the basins, producing a high flat surface. This peneplanation was finished during Oligocene or Miocene time. In Pliocene time, the same movement which raised the Coast Range farther west (Cascadian Revolution) began to raise the Rockies; this revolution reached its culmination in late Pleistocene times. This mountain building in the Rocky Mountain area was epirogeny rather than orogeny; that is, it was a quiet vertical uplift without buckling. Erosion of this uplifted area accounts for the present rugged topography of the Rockies. One result of this history is that many of the streams which developed on the old erosional surface kept their old courses and as they wore down their beds, they cut across different formations without regard to structure. Such streams are said to be superposed. They are out of adjustment with the structure, and are marked by canyons and open basins. Many such streams are to be seen in the Alaska Range.

In the far West two parallel mountain chains, the Sierra Nevada and the Coast Ranges, separated by a trough, came into existence toward the end of the Tertiary. The Sierra Nevada on the east is a great fault block 100 miles wide and 400 miles long. Its western side was depressed to form the great intermountain valley of California. The western mountain chain, the Coast Ranges, also extends from Mexico to Alaska.

In the southern Rocky Mountain area the Colorado Plateau was uplifted regionally. It is composed of gently dipping formations of Mesozoic age and older into which the rivers have incised themselves very deeply (Grand Canyon of the Colorado). The rocks of these formations stand in impressive mesas.

In the northwestern United States, the Columbia Plateau consists of built-up beds of numerous Tertiary lava flows of basalt which cover 200,000 square miles with a maximum depth of 5000 feet. Interbedded with them are sands, clays, and volcanic ash. The late Tertiary was a time of great crustal unrest, which is still continuing. (The Quaternary is not separated from the Tertiary on the basis of this mountain building, but on the basis of continental glaciation). The Cascadian orogeny continued through the Quaternary to the present, although it reached its climax in late Pleistocene times.

On other continents, uplift and mountain building took place on a scale comparable to that in western North America. The Andes, like the Rockies, were peneplaned during early Tertiary time, then elevated and dissected. The Alps, Carpathians, and Himalayas are the products of great thrusts from the south which buckled and up-arched former geosynclines. Lava flows and explosive volcanoes were active in many parts of the world, and toward the end of the Tertiary, the volcanic chain which arches around the Pacific was developed, forming what is now known as the "ring of fire".

Alaska - In Alaska, as elsewhere, the Tertiary sediments are predominantly terrestrial. In Southeastern Alaska, eocene sandstones and conglomerates overlain by, and interbedded with, volcanics are found. Some thin beds of coal associated with them have been mined on a small scale in the past. These sediments were laid down in alluvial fans, and later subjected to moderate tilting by mountain building forces.

Along the Gulf Coast in the Copper River region there lies a particularly well-studied group

of Tertiary rocks, consisting of terrestrial and marine sediments. In the Yakataga district, coal ranking from sub-bituminous to anthracite occurs in Miocene rocks (Bering River field). Around Katalla, oil is known to exist in Tertiary rocks. At the time the rocks were laid down the coast line was fluctuating, now withdrawing to allow terrestrial sediments to accumulate and then moving in to allow the sea to deposit marine sediments. Tertiary sedimentary rocks have been found on Middleton Island in the Gulf of Alaska, indicating their former great extent. Farther inland in the Copper River basin, Tertiary rocks are rare. A few areas of conglomerates, clays, and thin coals have been found, which were laid down in fresh water, but most of the Tertiary rocks of the area are volcanic in origin.

Farther west, in the Cook Inlet-Susitna region, Tertiary rocks occur near the head of the Inlet, extend up the Susitna and Matanuska Valleys, and cover the western part of the Kenai Peninsula. All of these rocks have much in common; they are terrestrial sediments composed of mudstones, sandstones, and conglomerates, with interbedded coal, which in parts of the Matanuska area have been raised in rank by igneous action and folding. In the Alaska Peninsula there are tremendous amounts of Tertiary rocks, both marine and terrestrial. Thin coal seams are found in some of the terrestrial beds and Alaskas developing petroleum industry is based chiefly upon oil and gas found in the marine members. The Aleutian Islands are composed entirely of Tertiary and Recent volcanics. Marine and terrestrial sedimentary rocks are also found on the Kodiak Island group.

In the Yukon River region there are three main areas of Tertiary sedimentary rocks: the north slope of the Alaska Range in the Bonfield and Kantishna districts; the Koyukuk-Dall River area; and the Eagle-Fortymile districts. Smaller areas of poorly consolidated gravels occur at other localities. (There is some evidence that Tertiary rocks formerly were widespread in the Yukon-Tanana Plateau). The Bonfield-Kantishna deposits were deposited during the Tertiary when clays, sands and gravels spread northward in a broad alluvial fan. Subsequent uplift in the Range has caused most of these rocks, which are poorly consolidated, to be eroded away, leaving them only in synclinal basins. A great quantity of sub-bituminous coal is interbedded with these rocks, for which reason they are called simply the coal bearing group. Overlying them is a poorly consolidated layer of gravel and sand of late Tertiary age called the Nenana gravel.

In the Koyukuk and Dall River areas Tertiary beds occur as scattered patches of fresh water deposits; they probably were of greater former extent. A belt of Tertiary conglomerates, sandstones, and mudstones extend from the Fortymile to the Circle district, containing coal seams and some gold. (The chief economic interest of this gold is that it contributed to later placer deposits).

Unconsolidated high level gravels in the Fortymile and Hot Springs districts are usually considered to be Tertiary in age, marking former drainage systems which have been broadly uplifted. Tertiary volcanics, as well as intrusive rocks, are found in the Yukon River region. The last great period of intrusion, one which brought considerable mineralization, occurred then. On the coastal plains of Seward Peninsula, marine sediments of Tertiary age are directly overlain by gravels of Pleistocene and Recent age, some of which have been mined for their gold content. Coal bearing terrestrial deposits also occur on the Seward Peninsula. Several islands in the Bering Sea, notably Nunivak, St. Paul in the Pribilofs, and Nelson, contain Tertiary sedimentary rocks, as well as large areas of Tertiary volcanics.

Tertiary sedimentary rocks occur in northwestern Alaska and northern Alaska. In the Kobuk valley they are in discontinuous patches, coal-bearing in some places, and are considered to have been formed on land. The northern Alaska beds are part of a series of marine sedimentary beds.

Economic Products - The economic products of the Tertiary period include petroleum, which is found in the Gulf Coast pool and the California pool, and in almost all the great oil fields of Europe and Asia. The oil of the Kenai peninsula field and the Katalla field in Alaska, as has been noted, occurs in rocks of Tertiary age. Most of the coal of western North America is of Tertiary age, but since this coal is of lignite or sub-bituminous rank, as are most Tertiary coals in other parts of the world, they are little used except in the regions in which they are produced.

The metalliferous deposition that accompanied the Tertiary intrusives constitutes one of the greatest metallogenetic epochs in the history of the earth. Gold, silver, and base metals were deposited on a world-wide scale in places too numerous to mention. Cripple Creek, Comstock, Potosi, the southwestern United States porphyry coppers, and many districts in Alaska are only a few examples.

Many non-metallic minerals were formed during Tertiary time, among them diatomaceous earth and lime phosphate.

Climate and Life - The climate at the start of Tertiary time was warmer than today, as is indicated by the sub-tropical and temperate plant fossils found in high latitudes. The climate cooled all during the period.

The outstanding feature of Tertiary life is the rise of mammals. The great dying at the end

of the Cretaceous left the reptiles represented by much the same forms as found today, while the invertebrates had almost completed their evolution to their present forms. The early Eocene mammals were characterized by a small ratio of brain to body weight, small size, and non-specialized features. Gradually the different orders, families, and genera developed, some dying out and some evolving and specializing. By the end of the period it is probable that ape-like men had appeared, while many varieties of horses, elephants, rhinoceros, camels, apes, dogs, cats, and other animals inhabited the earth.

THE QUATERNARY PERIOD - Toward the end of the Tertiary, mountains in many parts of the world were rising, volcanic activity was increasing and great warping and thrusting took place. This activity is called the Cascadian Revolution. As previously mentioned, this revolution still continues, so actually there is not the tectonic basis for dividing the Tertiary from the Quaternary as there is for separating the earlier periods from each other.

The elevation of the lands, with attendant disruption of the heat distributing currents of wind and water, caused extremes of climate. This uneven distribution of heat and precipitation, very probably in conjunction with other factors, unknown at present, caused ice to build up in certain centers of precipitation. The outward migration of ice from these centers, until a maximum of thirty two per cent of the land area of the earth was covered in four major successive advances and retreats, constituted the Ice Age. The time between the first advance of the ice until the last retreat is called the Pleistocene epoch of the Quaternary period; it occupied about ninety five per cent of the period. The remaining time, in which we are living, is called the Recent epoch. As glaciers today cover about ten per cent of the earth's surface, the earth may be in an interglacial period, between the fourth and fifth glacial periods, and not at the start of a new epoch. Unfortunately for this system of subdivision, the ice did not leave everywhere at the same time. In the United States, the continental glaciers have been gone for about 10,000 years, but at higher altitudes and latitudes the ice was present in comparatively more recent time. As every Alaskan knows, in certain areas it is present today. For this reason, some geologists prefer to consider that the Pleistocene still continues, and that Recent time is part of the Pleistocene.

In North America the Ice Age, or Pleistocene epoch, is divided into subepochs (called ages) corresponding to advances of the ice and its subsequent melting. Since there were four main advances, there are four ages, which in North America are named for the localities in which their deposits were first studied. In Europe the corresponding ages have different names. The relationships of these ages are shown in the following table.

<u>NORTH AMERICA</u>	<u>EUROPE</u>	<u>ESTIMATED TIME BEFORE PRESENT YEARS</u>
Recent	Recent	4,000-10,000
Wisconsin (4th) glacial	Wurm	Older than 25,000
Sangamon Interglacial	Riss-Wurm	100,000
Illinoian (3rd) glacial	Riss	110,000
Yarmouth Interglacial	Mindel-Riss	
Kansan (2nd) glacial	Mindel	180,000
Aftonian Interglacial	Gunz-Mindel	
Nebraskan (1st) glacial	Gunz	300,000 to 600,000

The last (Wisconsin) age is divided into 4 sub-ages as follows:

<u>Age</u>	<u>Sub-Age</u>	<u>Estimated Elapsed time, Years</u>
Wisconsin glacial	Mankato	11,000
	Cary	13,000
	Tazewell	20,000
	Iowan	Older than 25,000

The problem of dating the end of the Wisconsin Age is similar to that of dating the Pleistocene epoch. However, there is recognized a world-wide period of warming, the thermal

maximum, which occurred about 4,000-7,000 years ago. At that time the continental glaciers disappeared from North America and the valley glaciers from the United States. The time which has elapsed since the thermal maximum is sometimes called the Little Ice Age. Clearly the average temperature has decreased in the past 4,000 or 5,000 years.

The dating of Wisconsin and Recent events is facilitated by radioactive carbon dating, analogous to radioactive dating with uranium. By this method dates within the past 35,000 years can be determined accurately.

The ice originated in three places: Northern Canada, Scandinavia, and Siberia. In North America there were two centers of ice accumulation: the highlands and mountains of north-eastern North America and the high regions of the West. The eastern center gave rise to the Laurentide Ice Sheet; the western to the Cordilleran Glacier Complex. The ice, at one time or another, covered almost all of the continent south to approximately the Missouri and Ohio Rivers. The only major unglaciated areas north of this line are the Northern Alaska plain and the Interior Alaska lowlands.

The changes to the landscape and to man's economy wrought by these invasions of ice cannot be overemphasized. As the glaciers advanced, they scoured the earth, sometimes digging into bedrock; then, as they approached the limits of their advances, they dropped the material. Sometimes this formed rich soil, but in places it left behind miles of boulders which render the ground unfit for most uses. In the field of mining and prospecting they likewise exercise a great effect. Where bedrock is exposed by ice scouring, the search for lode deposits is facilitated, but the possibility of rich placers is reduced almost to zero. On the other hand, glacial drift may mask all signs of either type of deposit. (See Chapter 6 for a discussion of the effect of glaciation on placer deposits).

The most prominent features connected with continental glaciation were formed during the last retreat. The retreating ice in many places dammed up large lakes of meltwater. One such great lake was Lake Agassiz in Manitoba, North Dakota, and Minnesota, which existed until the ice had melted back far enough so that the lake could drain north. As would be expected, the drainage patterns were greatly affected by the advance and retreat of the ice, as well as by the great quantities of water which the streams were forced to discharge during the melting stage.

The accumulation of water in the form of glacial ice removed water from the ocean basins. It is estimated that at the time of maximum glaciation the sea level was 300 feet lower than at present. If the present glaciers of the world were to melt, the sea level would rise 100-200 feet. Another result of the accumulation of ice on the continents was the depression of the land under the overlying weight. In Central Canada this depression was as much as 1,000 feet, as indicated by elevated lake shorelines. The land has been rising by elastic rebound ever since the melting of the glaciers.

During Recent time, the present channels of streams have been cut, and the gravel along the surfaces of stream valleys; the soil of the fields; and the thin cover of creep on hillsides has developed. These features are products of processes continuing today. As noted above, another widespread feature of Recent time, is the rising of land from which the glaciers melted, coupled with a rise in sea level as the water concentrated in the ice returned to the sea. The mountain building and volcanism of Tertiary time extended into the Quaternary with hardly a break, and continues to the present day.

Alaska - In Alaska the detailed work necessary to recognize different glacial ages has been done in a few places. This work indicates that in some localities there were six advances, two pre-Wisconsin, three Wisconsin, and one post-thermal maximum in age. Ice originated in the Brooks Range and in the mountains from the Alaska peninsula to Southeastern Alaska. Smaller centers of accumulation occurred on Seward Peninsula, and near Bristol Bay. The area between the Brooks and Alaska Ranges was unglaciated except locally. In Southeastern Alaska, the advance started from the mountains, flowing both east and west. After the ice had met the ice advancing from the Rockies, it built up to such a depth that it flowed back over the coastal mountains toward the Pacific, scouring the fjords which comprise one of the dominant features of the coastline today. Ice connected with this glaciation formed in the mountains along the Gulf Coast (St. Elias, Chugach, Aleutians) and in the Alaska Range, and advanced north and south. The ice moving south entered the sea as an ice shelf, and that moving north melted along the northerly flank of the Alaska Range. Similar, but less extensive glaciation developed in the Brooks Range, and isolated areas of glaciation developed in the higher parts of the area between the two ranges. Most of the Arctic Coastal plain was unglaciated, and the unglaciated area in the Interior extended a short distance into Yukon Territory. This lack of glaciation in such high latitudes was due to the slight precipitation, which also accounts for the fact that less ice formed in the Brooks Range than in the Alaska Range. Fig. 6-11 shows the approximate limits of Pleistocene glaciation in Alaska.

So far the only phase of the Pleistocene epoch in Alaska that has been considered is glaciation. Other events occurred during the epoch, related to glaciation because of the effect of the surrounding ice upon the climate. (Such effects are called periglacial effects). During and after the ice ages, large amounts of silt were blown from the regions adjacent to

the ice, and deposited in many places in the Interior. The silt was derived from the products of glacial scouring that were deposited on the banks and bars of the larger streams, especially the Tanana River, and redeposited by the wind as a blanket of varying thickness over Interior Alaska. Later, erosion removed much of the silt in the lowlands while creep and wash brought silt down from the hillsides and deposited it in the lower valleys as muck. Mixed with this reworked silt are much vegetation and the bones of animals. Locally vegetation accumulated to depths of several feet, forming layers of peat. Great quantities of ground ice are found in the muck. (See explanation for the formation of ground ice in Chapter 6).

Another phenomenon associated with past glaciation is the permanently frozen ground, Permafrost, of Alaska. Areas of such ground are found in many places north of a line passing through points having an annual average air temperature of about the freezing point of water. This suggests that the permafrost may be forming wherever the mean annual temperature is below freezing, but undoubtedly much of the ground froze during the Pleistocene epoch. This is shown by the excellent preservation of some of the animals that lived in glacial times. Where even the flesh is preserved, the ground surrounding it must have frozen soon after the animal died, and stayed frozen due to further burial the next season. It is known, however, that during the thermal maximum some of the permafrost thawed, and has since refrozen.

Most of the placer deposits of gold and other minerals in Alaska were formed during the Quaternary. Many of the placers of that time were scattered by the glacier ice, some to be lost forever as economic deposits, some to be reconcentrated by interglacial and Recent erosion cycles. (See Chapter 6 for a discussion of the effects of glaciation on placer deposits).

Economic Products - The economic products of the Quaternary period are those which have resulted from the breakdown and concentration of earlier ones. Most placers formed in the Pleistocene, although a few date from Tertiary times, especially in California. The buried placers and old bench placers, overlain by muck, as well as those which have undergone several reconcentrations, obviously date from Pleistocene time; while those forming in valleys today, or those formed from the reconcentration of glacial deposits are Recent in age. Other economic products include sand and gravel.

Climate and Life - The climate of Quaternary time, viewed as a whole, has been much like that of today. During each of the ice advances the climate was colder and moister than today. The interglacial periods, on the other hand, all of which were much longer than the Recent, were at least as warm, and may have been warmer than the present climate.

The life of the Quaternary has had a distinctly modern aspect. North America had as many big game animals during the Pleistocene as Africa has today, including several species of elephants and buffalos. Many of these were larger than those of today. Although many species of Quaternary mammals are now extinct, their similarity to existing ones is easily recognized.

During the Quaternary, the flowering plants spread out until they are now found living through a very great range of elevations and climatic conditions.

Flint objects which very likely were used by man have been found in Pliocene beds in England. What type of man made these objects is unknown. During the Quaternary, however, man developed through several species, as is evidenced by numerous fossil bones found in Quaternary deposits in several parts of Europe, Asia, and Africa. Sometime during the last ice age, the forerunner of Modern man appeared. Aside from his greatly enlarged brain, which makes him unique among all things that have lived since the beginning of life on this planet, man is relatively unspecialized. His feet are not adapted for speed in running nor his hands for swinging through the trees, nor his fur for protection from cold. His two greatest assets, again aside from his brain, are his ability to walk with his hind limbs alone, leaving his arms free for other occupations, and the fact that his thumbs oppose his other fingers, allowing him to handle tools easily.

CONCLUSION

In this chapter a few events in the history of the earth have been noted. Obviously, the subject of historical Geology cannot be covered in such a short space. It is hoped that this brief outline will at least give the reader an idea of what historical geology is, so that by further reading he can study in more detail some of the periods in which he might be interested.

To anyone making his first acquaintance with historical geology, especially in a summary such as this, a variety of new and confusing impressions are bound to present themselves. This is because the length of time involved is far greater than can be grasped by one used to thinking in terms of a lifetime or even in terms of recorded history. The British astronomer, Sir James Jeans, has said, "Let the height of the Woolworth building represent geologic time. We may then lay a nickel on its tower to represent the time of human existence. A thin sheet of paper will represent all historic time!"*

* Reprinted with permission from Schuchert and Dunbar, *Textbook of Geology, Historical Geology*, Copyright 1941, John Wiley and Sons, Inc.

References

- Dunbar, Carl O. 1959, *Historical Geology*, Second Ed: John Wiley and Sons, Inc., New York
- Emilliani, Cesare, 1955, Pleistocene Temperatures: *Jour. Geol.* Vol. 63, p. 538-578.
- Flint, Richard Foster. 1957, *Glacial and Pleistocene Geology*, John Wiley and Sons, New York
- Smith, P.S., 1939, *Areal Geology of Alaska*, U.S. Geological Survey Prof. Paper 192

Chapter 6

SURFACE FEATURES OF THE LAND; GEOMORPHOLOGY

INTRODUCTION

The study of the forms of the surface features of the land is geomorphology, (from the Greek *geos*, earth, plus *morph*, form). Physiography sometimes is used in the same sense, but it also takes in the study of the atmosphere and ocean basins, as well as the lands. Certain forms occur in nature, such as stream valleys, cliffs, or rounded hills, each of which is the product of particular processes acting on particular structures. When the processes are repeated on the same structures, similar land forms result. The study of the land forms and their relationship to process and structure constitutes the work of the geomorphologist. Probably no other branch of geology can be practiced more often or affords more satisfaction to the observer than geomorphology.

Topography is the configuration of the surface of the land; it is merely descriptive, making no attempt to discover causes. Topography is usually expressed as a topographic map, the most common and useful of which is the contour map. On the contour map, points of equal elevation are connected by a line. The surface of an area can be represented by several such lines, separated from each other by a chosen vertical distance, called the contour interval. The elevation of a point is its height above sea level; the relief of an area is the difference in elevation between the lowest and highest points in the area.

The different relief features studied in geomorphology are very broadly divided into three ranks of magnitude. The first order relief features are the continents and ocean basins. Second order relief features are mountain chains, plains and plateaus. These are constructional forms, or those which came into being by constructional processes. Third order relief features are such things as valleys, lakes, cliffs, ridges, etc. These are destructional forms, or those formed by carving (destruction) of constructional forms. It is mainly with third order features that this chapter deals.

Students of geomorphology have discovered that several broad classifications of landscape can be made, depending on the climate and erosional agent that shaped them. In this chapter, geomorphological features are divided into the following classes, listed, in general, in order of their importance in Alaska:

1. Processes and Surface Forms of Humid Regions; the Fluvial or "Normal" Cycle.
2. Processes and Surface Forms of Cold Lands; the Fluvial Cycle modified by a cold climate.
3. Processes and Surface Forms of Glaciation; the Glacial cycle.
4. Processes and Surface Forms of Arid Lands.
5. Processes and Surface Forms of Coastal areas; the Marine Cycle.
6. Processes and Surface Forms in Underground Solution Areas.
7. Processes and Surface Forms Connected with Constructional Forces.
 - a. Fault Structures
 - b. Volcanic Forms
 - c. Coral Structures

The first six processes are destructional forms; that is they operate to break down and cut into the surface. The three forms listed under number seven are constructive; that is, they are built up into their various shapes by earth movements or animal activities.

Each of these processes may act upon any one of several different types of second order or third order relief. For example, the fluvial cycle operating on mountains produces different results than when operating on plains. Each also may operate upon any one of the numerous structures discussed in Chapter 4.

In previous chapters it has been explained that the surface of the earth has undergone many uplifts and crumplings. The uplifts result in many different structures: anticlines, synclines, domes, fault mountains, or large elevated plateaus, or a section of the continental shelf raised to form a sloping featureless coastal plain. Down-warpage, downfaulting, or a lowering of sea level leaves adjacent areas relatively high.

Any of these occurrences (diastrophism) leaves the uplifted areas in a position to be attacked immediately with renewed vigor by agencies acting in conjunction with gravity to tear down the land, since the intensity of erosion increases with relief. In geomorphology it is said that this has started a new erosion cycle. (Erosion is the breaking down and removing of the material of the earth's surface). According to the cycle theory, a landscape goes through cycles, starting with relative uplift, followed by the stages of youth, maturity, and old age. It is believed that these stages can be present in landscapes produced by each of the different

processes. (It is doubtful, however, if certain processes, i.e. glaciation have produced landscapes of old age). In the fluvial process, the normal one operating under the influence of running water, all of the stages can be seen readily.

Erosional attack is intensified by relief, or the vertical distance through which the products of erosion must travel. This distance is controlled by the base level, the level below which no erosion can take place. It usually is the level of the water into which the drainage of an area flows, but it can be some other level, as will be explained. The sea, of course, is the ultimate base level below which erosion by water or wind cannot cut, except in an inland arid basin where evaporation allows the basin to exist (for example, Death Valley). Of more importance in the interior of an area are regional base levels, controlling regional erosion, or local base levels, controlling the erosion in restricted areas. When a stream or an area is lowering itself by erosion, it is degrading; when filling in, it is aggrading.

Some examples best illustrate local base levels. The local base level for the southern part of the Yukon-Tanana plateau is the Tanana River. The Yukon is the regional base level for the south slope of the Brooks Range, and the Koyukuk is the local base level for the streams in its catchment basin. Local base levels are temporary, because sooner or later, uplift, filling in, or downcutting changes them. Thus, the deep filling of the Tanana River Valley has raised the regional base level and caused the tributary streams on the north side to fill in (aggrade) their lower courses. In the Brooks Range, where the major valleys were until recently filled with ice and glacial debris, the mouths of the tributary streams became choked with mud and gravel. The clearing of such fill from the main river valleys after the ice melted has lowered the local base level of the tributary streams, and V-shaped valleys have been cut into the lower courses of these streams as a result. Open cut placer mining illustrates very well the effect of a changing base level on erosion. When a bedrock drain is dug, it lowers the local base level of all that part of the creek above it; and the hydraulic miner takes advantage of this lower base level to excavate his cut. Conversely, when the creek is worked out, the miner leaves, the drain sloughs in, and the base level rises, allowing the cut to fill in.

When an area has been uplifted or its local base level has been lowered so that erosion is accelerated, it is rejuvenated. It is evident that rejuvenation may take place at any stage in the erosional cycle; if it takes place before the end (old age), the cycle is interrupted. If a cycle goes to completion before being rejuvenated, the end product is called a peneplain - a large plain leveled almost flat at the regional base level by whatever process is operating (usually the fluvial process). Occasional hills of resistant material rearing themselves over the peneplain, are called monadnocks, after the one first described, Mt. Monadnock, in New Hampshire. Traces of old peneplains are sometimes seen where the peaks of an uplifted area have approximately the same elevations. The process of cutting a peneplain is to peneplane.

PROCESSES AND SURFACE FORMS OF HUMID REGIONS: THE FLUVIAL OR "NORMAL CYCLE"

In most parts of the world, running water is the chief destructional agent shaping the surface of the earth. The water that acts in the fluvial process is meteoric water; that is, water that falls, precipitation. It soaks into the ground and stands at some level, depending, among other factors, on the amount of precipitation. This water is called the groundwater. The upper surface of the groundwater is the water table; where the water table reaches the surface, lakes and streams exist. Although there is a tremendous variation in the amount of water available on different parts of the earth, the forms evolved in general are similar, except in the arid regions which receive rainfall only in torrential cloudbursts every few years.

The mechanics of shaping the surface fall into two classes, preparation and transportation. By preparation is meant the processes by which the solid material of the crust, the bedrock, is broken down into particles small enough to be moved. These broken pieces of bedrock plus other loose (organic) material constitute the mantle rock, the loose unconsolidated cover of the earth. Under transportation fall all the processes by which the particle is carried away.

Preparation

Preparation embraces several processes, all of which come under two headings, abrasion and weathering.

ABRASION - Abrasion is the wearing away of the bedrock by scouring with other bits of rock. These bits of rock may be moved by water, wind, or ice.

WEATHERING - Weathering is the breaking down of the bedrock by exposure to air, water, or other components of the atmosphere. There are two types of weathering; chemical weathering, or decomposition, in which the composition of the rock is changed; and mechanical weathering, or disintegration, in which the bedrock is broken

into small pieces without chemical change. A warm humid climate favors decomposition; much of the weathering in the humid coastal areas of Alaska is decomposition, but most of the weathering in interior Alaska is disintegration.

Decomposition is accomplished mainly by carbon dioxide, oxygen, and water vapor. Disintegration is accomplished by alternate freezing and thawing with the seasons, or by warming and cooling with day and night, or by other agents such as plant roots, freezing water, or gravity. Weathering of a rock is very much faster if it is exposed to the elements than if it is covered by mantle rock, and a thick covering reduces weathering almost to zero. In a few places weathering has been stopped by mantle rock accumulation, but almost always some transporting agent removes the accumulated detritus (fragments derived from rock breakdown), allowing weathering to proceed.

Transportation

Included under transportation in the fluvial process are mass wasting and removal by running water.

MASS WASTING - Usually the products of weathering, before they are in a position to be moved by running water, undergo some form of mass wasting. By this term is meant the mass movement of the mantle rock downslope by gradual or rapid movements. Gradual movements occur on relatively gentle slopes by creep, the imperceptibly slow moving down slope of the cover under the influence of gravity. An abundance of water hastens creep by lubricating and making the soil more fluid. Also because any process that disturbs the cover on a hillside can only result in downward movement, frost heaving by alternate freezing and thawing hastens creep. When water freezes, it expands, pushing a particle of material outward at right angles to the slope; but when it thaws, the particle drops straight down, giving a downward vertical component to its movement. The vertical component of expansion is termed heave; the horizontal component, thrust.

In Alaska, as well as in other northern countries, a form of creep called solifluction (soil flow) is very effective in mass wasting. Solifluction is the "slow downslope movement of presumably saturated material under the action of gravity, probably in conjunction with frost action". It is important in Alaska because when the permanently frozen ground (permafrost) thaws to a slight depth during the summer, the water in the thawed soil cannot escape, and the ground becomes almost saturated and the uppermost layer flows as a thick liquid. On almost any slope above timberline in the areas of permafrost this process can be observed. The ground actually flows down in gigantic bulbous ripples, in places at an estimated rate of about one inch per year. The result is a mixture of mud and angular rock fragments, with mud or muck usually predominating. Frost heaving, which occurs each time the mass is frozen (several times each spring and each fall), also probably contributes to the movement.

Another form of gradual mass wasting is the rock glacier, a slow moving stream of rocks flowing down a more or less restricted path, fed by an area of active disintegration on a mountain. The rocks are solidly frozen together by ice in the interior of the rock glacier.

Mass wasting is also accomplished by more rapid movements, sometimes of catastrophic proportions: The accumulation of rock fragments at the base of a cliff or steep slope is called a talus, and the material composing it is sliderock. The talus constantly gains material from above and loses material at the bottom by weathering and creep. Toward the bottom, the grade becomes flatter and the material finer, sometimes grading into soil.

Sometimes on steep slopes in rugged country, masses of mantle rock slide down bodily as landslides. The landslide may consist of coarse rocks, bedrock, or soil, sliding on some plane such as a weathered contact or fault plane. It may also consist of saturated soil that slumps under its own weight. Landslides of the first kind occur on steep slopes in Alaska, and sometimes temporarily block small streams. Slides are usually easily identified because trees stand at odd angles on a hummocky, lake-pocked topography at the base of the slope. This topography is called "landslide topography."

Still another type of mass wasting is the mudflow, often occurring in arid or semi-arid climates, which results from the saturation of fine rock particles on a hillside after a heavy rain. The viscous mud at the front of the flow dams the water behind and the whole mass moves down-slope. If such a flow comes down a narrow valley and emerges into a broad flat, the dammed water may be released, causing a disaster if human habitation happens to be in the way. Thus mudflow may be gradual or rapid mass wasting. Mudflows are midway between solifluction and running water in their manner of movement.

All the products of mass wasting are sometimes referred to as slide, the larger fragments of which are called sliderock. Slide exhibits little rounding; this characteristic is in marked contrast to the rounded nature of the material after transportation by running water. Such material, rounded by water is known as alluvium, alluvial material, or wash. Slide rock sometimes develops rounded edges by weathering. Granite is especially susceptible to rounding by weathering.

TRANSPORTATION BY RUNNING WATER - Mass wasting moves unconsolidated material

from the hills into the valleys, which, without some means of removal, would soon become filled in. In the fluvial process here under discussion, the running water flowing in streams - rills, creeks and rivers - is the removing agent. Streams occupy valleys (troughs cut into bedrock). The sides of the valley usually are covered by the products of mass wasting, and the valley bottoms by alluvium lying above bedrock. If the valley is downcutting, the bed load of alluvium for a considerable depth is transported downstream. (See the formation of placers, Chapter 7). Only during the early stages of a cycle does the water of a stream run upon bedrock.

The largest rivers receive the runoff from very large areas (the Yukon River drains about one fourth of Alaska), smaller rivers flow into them, large creeks flow into the small rivers. If the drainage pattern is followed into the hills, it is found that the large creeks have small creeks entering them, and that the small creeks have intermittent rills entering them. Each of these streams, from the large rivers to the small rills, receives the water from a definite area called the catchment basin of the stream. (The use of the term watershed, having the same meaning, should be discontinued, as it also means the dividing line between catchment basins). Most of the water reaching the larger streams, of course, comes from their tributaries (streams flowing into larger streams), but a certain amount reaches them by groundwater and surface water trickling down the sides of the valleys. In the smaller streams, this trickling of ground water and surface water from the sides provides proportionately more water than do the tributaries, and in the smallest streams it is only this trickle (runoff) which furnishes the water. The smallest streams run only during the spring thaw or rainy periods. The water stored as groundwater provides a reservoir that extends the periods of flow.

All streams have a certain amount of transporting power; that is, they are capable of moving a load of solid material in suspension. In low water a sluggish stream moves only very fine material; but during high water, or in reaches of a stream having a steep gradient, the stream may move gravel and boulders. This load carried by the streams is furnished by the mass wasting of the land within the catchment basin, and the two working together produce the configuration of the land peculiar to the fluvial cycle.

Any stream continually strives for equilibrium, the state in which it has just sufficient gradient so that it may transport its load. A steep mountain stream has more gradient than necessary to transport its load; therefore it cuts down in its upper parts and reduces its grade. A stream which suddenly cuts into a new source of easily transportable material at its head distributes it along its length until its grade becomes steep enough to allow it to transport the added material. Both are establishing equilibrium. A stream near equilibrium is said to be graded. Obviously a stream graded throughout its length cannot contain waterfalls or rapids, although portions of a stream between rapids may be at grade.

The Fluvial Cycle

The fluvial cycle is started by uplift relative to the base level. The rise of a portion of the continental shelf to above sea level, the draining of a lake, or the birth of a mountain chain, may initiate the cycle. Uplift of a land with already developed drainage patterns may result only in rejuvenation, that is, renewed downcutting of the pre-existing streams. If, however, uplift is rapid enough, the old drainage may be disrupted and a new pattern established.

UPLIFT - Drainage upon a newly uplifted land area is developed as follows. At first rain water moves down the slopes in sheets of runoff (sheetwash), but soon the water becomes concentrated, and the increased eroding power excavates gullies. Excavation widens and deepens the gullies, thereby causing several to be consolidated into one. The gradients of the gullies increase headward, and they lengthen themselves. Gradually they become larger, and smaller tributary streams form as feeders to the larger ones. If the original slope were a gently sloping surface of small relief, such as an emerged coastal plain, an outwash fan, or an old lake bed, the direction taken by the streams is purely accidental, and the pattern they develop resembles the veins in a leaf; such streams are called *insequent* and the drainage is called *dendritic* drainage. If, however, some relief is present upon the new surface, the stream pattern develops down the slopes or in the low parts; or if a particular type of rock structure exists, it may control the new drainage. Any stream which develops upon the original slope of newly created land (an initial slope) is a *consequent* stream.

YOUTH - In the stage of youth following the start of a new cycle, the valleys are narrow, shallow, and V-shaped, with their floors little wider than the streams which they contain. As mass wasting gradually feeds material from the sides for the streams to remove, the valley sides become less steep, and the uplands between valleys become smaller in area. This interstream area soon becomes the divide (or watershed), between two catchment basins, and as the streams on opposite sides of the divide erode unequally, the divide shifts one way or the other, forming, in time, a curved ridge. The fluvial cycle is a continuous process and it is difficult to state when a stream passes from youth to maturity; but by definition, when all of the interstream has been eroded away, leaving sharp divides, maturity has begun. From this time on, the divides become lower and more rounded.

MATURITY - During the stage of youth, the stream has been actively downcutting its valley and eroding headward. With decreased gradient much of the energy in the stream becomes available for sidecutting. As the stream swings around curves in the valley, it strikes first one bank and then the other, abrading and undercutting them. The stream, as it sweeps past these cutbanks, has its greatest velocity. In the slack water on the insides and downstream sides of the curves, the solid material in suspension is dropped to form banks of silt, sand, and gravel. As the swings of the stream cut on the outer and upstream sides of the curves, the curves gradually migrate downstream, leaving the valley wider than before. The banks on the convex sides of the curves slope toward the streams as slip-off slopes. Gradually, a slowly widening valley floor is cut from bedrock and covered with alluvium. This rock-cut valley bottom is called the strath; that part of the strath actually occupied by the water is the channel. When the strath reaches a width greater than the diameter of the stream curves, the valley is mature, and the curves are called meanders. When this stage is reached, most of the energy of the stream is spent in reworking its own alluvium, although sidecutting of the bedrock walls still continues slowly. The meanders now are very curved, and certain portions of the stream may actually be flowing up-valley. The stream may break across the narrow neck of land on the inside of a meander to form a slough. Because the gradient of the slough is greater than that of the meander, the meander may be cut off, and the water in it become stagnant, a crescent-shaped oxbow lake. Oxbow lakes are later dissected by other meanders working the valley. The flats of the Tanana, Kuskokwim, and Yukon Rivers in Alaska afford endless examples of meanders and oxbow lakes. Fig. 6-1 shows a meandering stream with numerous oxbow lakes.

A mature stream occupying a wide valley consists of a strath, a channel, and sloughs. During times of flood, the water overflows the banks of the channel to occupy the flood plain, which may or may not consist of the entire strath. As soon as the water overflows its banks and begins to spread out over the flood plain, the decreased velocity causes it to drop part of its silt load, building up natural levees, which rise above the rest of the valley floor on either side of the channel.

The alluvial material of the valley filling consists of gravel, sand, and silt. The gravel and

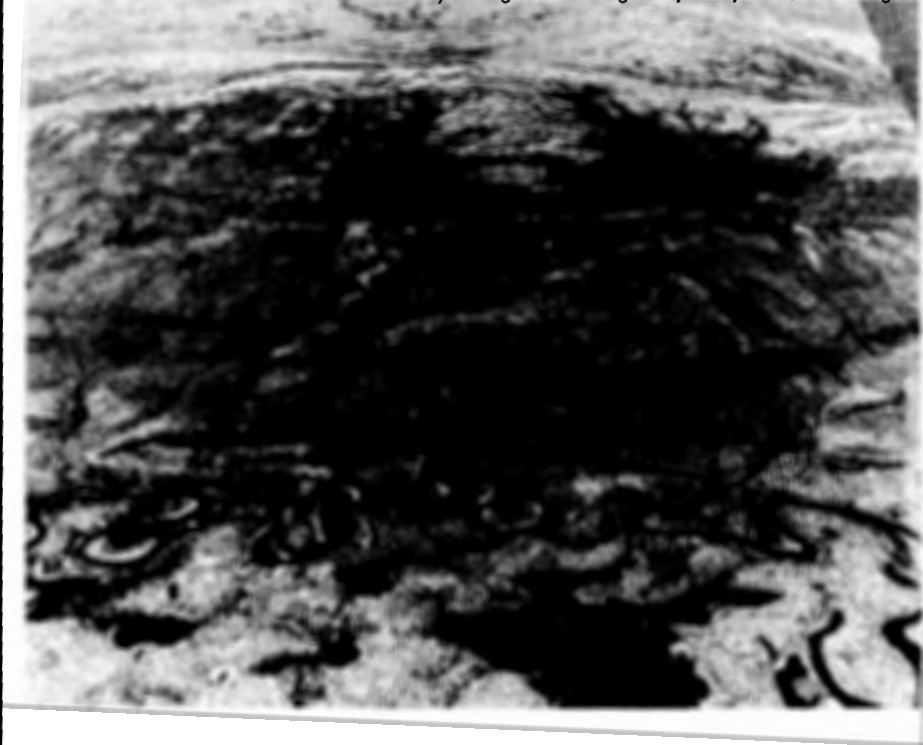


Fig. 6-1. - Meandering Stream with Oxbow Lakes and Cutoffs.

sand are deposited by the swift current of the channel in high water, but the silt is laid down in slack water. A very heavily laden stream may choke its channel and be forced to occupy an intricate network of shallow channels. This process is called braiding, and may be observed on most of the Alaskan streams that have glaciers at their heads. Bars are areas of sand and gravel, dropped by streams where the current slackens; they may be swept out by the next high water.

OLD AGE - As the major streams in a region become mature, occupying wide flat straths filled with oxbow lakes, and the divides between them become low and rounded, the region enters old age. Erosion is now very slow; it may require more time to remove the last few feet above base level than it took to remove all that which had been removed previously. The divides are low, the streams are sluggish, tributaries are few, and the region takes on the appearance of a flat, gently undulating plain, with here and there a remnant of the bedrock rearing above the rest of the country as an isolated mountain. This ultimate stage in the fluvial cycle will be recognized as a peneplain (almost a plain) and the hills as monadnocks. Fig. 6-2 shows cross sections of streams in different stages of development.

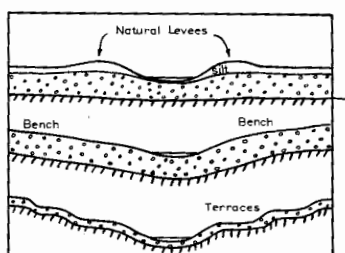
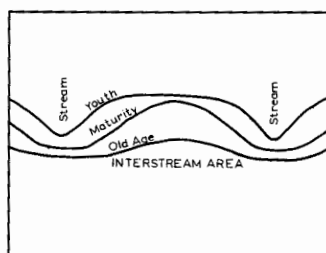


Fig. 6-2. - Stages in the Development of Streams

Fig. 6-3. - Stream Sections

The cycle, from the initial stage to old age, is rarely completed. More often it is interrupted by uplift, downwarping, faulting, glaciation, covering with windblown material or by some other agency. These interruptions may simply rejuvenate the old streams, or they may result in a completely new drainage pattern upon the old land surface. Uplift and rejuvenation of a stream causes it to rework its own alluvium; if the stream contains a placer, the placer may be enriched. If a shelf is left beside a downcutting stream, it is called a terrace or bench. Natural levees, benches, and terraces are shown in Fig. 6-3.

Relation Of Streams To Each Other

Two streams eroding headward toward each other from opposite sides of a ridge gradually reduce the divide between their heads to a saddle. As the saddle becomes lower, it may become a pass. A stream whose valley is lower than that of its neighbor may break into the higher stream's drainage basin by headward erosion. When this happens, that part of the higher stream above the point where the lower stream breaks through is diverted into the lower stream. This result is termed capture, stream piracy, or beheading. In time, if the capturing stream is much lower than the beheaded one, some of the drainage of the captured stream below the point of capture may be reversed to flow into the capturing stream. As a stream which has captured another commonly makes a sharp bend at the point of capture, the term elbow of capture is often used to describe the point. The increased gradient above the elbow of capture may cause waterfalls and gorges to develop, and may allow the stream to cut into bedrock. These indications of youth in an otherwise mature region should put the prospector on the lookout for other signs of capture. Fig. 6-4 shows a capture.

Waterfalls And Rapids

Waterfalls and rapids are indications of youth in the fluvial cycle, and also may mean that the cycle has been interrupted. An understanding of the conditions that cause them to form is of great value to the prospector in determining the geomorphic history of the region in which he is working, which in turn, has an important bearing on his search for placers.

A very steep gradient is, of course, the ultimate cause of all falls and rapids. A barrier of resistant rock crossing a stream may cause a falls to develop, or if the stream can cut into it, a rapids. Cap rock falls result where a stratum of resistant rock overlies easily eroded rocks; the stream plunging over the falls retreats, leaving a gorge; Niagara, for example.

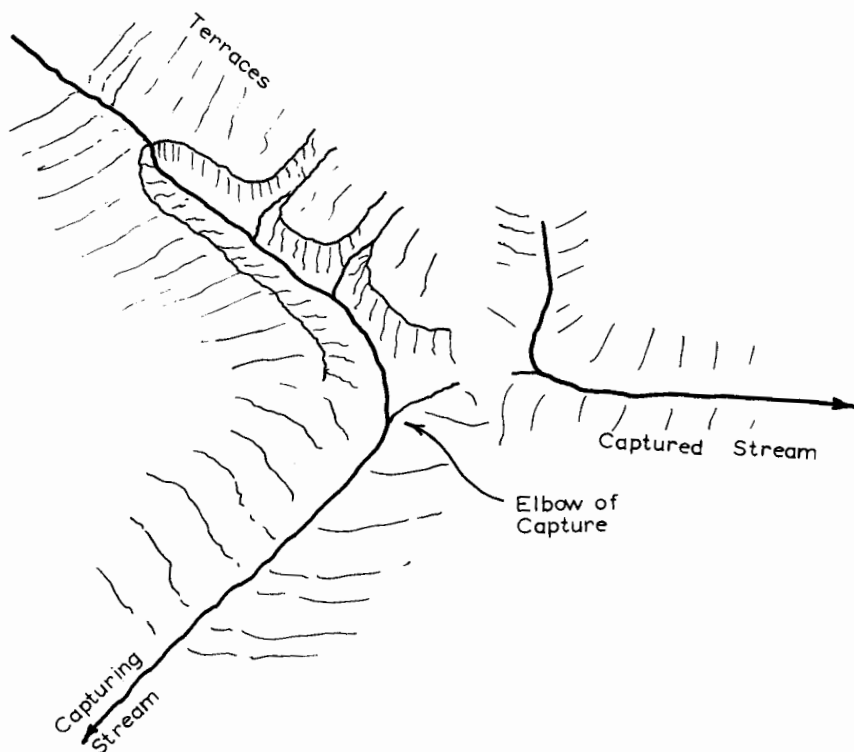


Fig. 6-4. - A Stream Capture in the Brooks Range

According to Playfair's law, most tributary streams enter master streams at the same level as the large streams, in what is known as an accordant junction. (A discordant junction, conversely is one in which a tributary enters at a high level, by a falls). Under certain circumstances, however, discordant junction falls form. By far the greatest number are caused by deepening of the master stream valley by glaciation. It is believed by some, however, that a few may be due to acceleration of the master streams by tilting, or greater erosive power of the master streams due to a much greater supply of water. Usually, this last process results in a gorge or rapids, rather than a falls.

Faults of significant vertical displacements also cause waterfalls to appear in the stream coursing them.

Drainage Patterns

The streams of a region that is undergoing erosion through the fluvial cycle follow many patterns, depending on the land surface upon which they were formed, and the underlying rock structure. Dendritic drainage, developing on a gently undulating plane surface, has already been defined. Radial drainage develops on the sides of a central dome or mountain and looks like the spokes of a wheel. Annular drainage forms a roughly circular pattern around a central mountain. Parallel drainage develops where streams flow down a uniform slope, as across a coastal plain toward the sea. Trellis drainage develops in a region of parallel folds and is made up of streams parallel to the folds, with many tributaries entering them at right angles. Rectangular drainage develops in a region where jointing and faulting divide the bedrock into rectangles, the streams following the lines of weakness produced by the fractures. Drainage patterns are shown in Fig. 6-5.

Streams that form a drainage pattern controlled by the structures of the area are said to be adjusted to structure. Any of the drainage patterns mentioned above are in adjustment if they occur in conjunction with the proper structure. For instance, the dendritic pattern on a surface of flat lying sediments or the trellis pattern in a region of parallel fold mountains, is

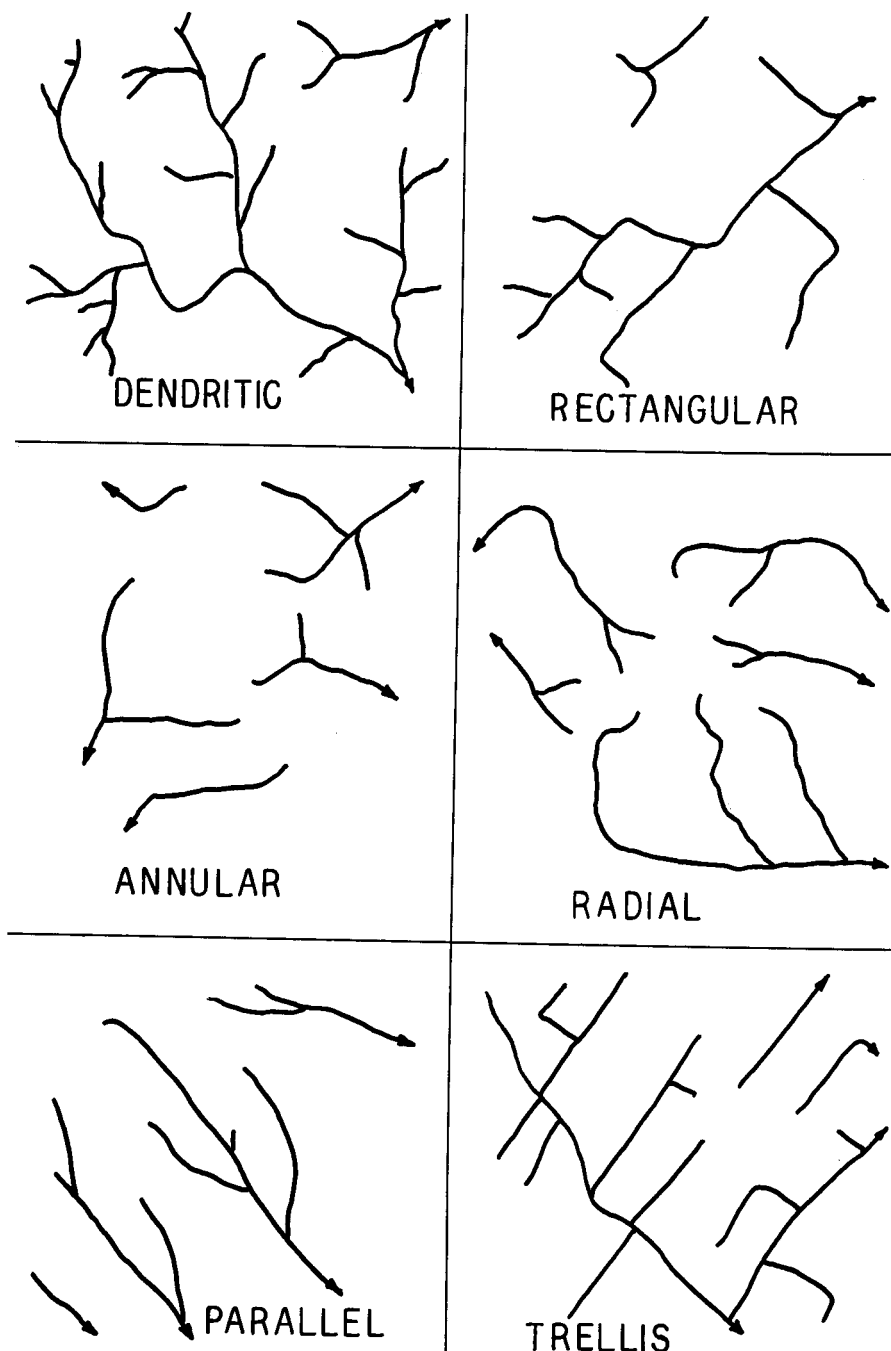


Fig. 6-5. - Stream Patterns

normally expected. What, however, does a dendritic pattern in parallel fold mountains, or a radial pattern in a flat region indicate? These patterns are out of adjustment and clearly indicate interruption of the cycle, although an interrupted cycle need not always produce non-adjusted drainage. One way in which non-adjusted drainage comes into being is by superposition, in which an original drainage pattern is maintained while the streams cut into an underlying structure.

The easiest way to illustrate superposition is by an example. In the Bonfield district in the foothills of the Alaska Range south of Nenana, a well developed dendritic stream pattern drains parallel fold mountains. This drainage pattern was established during late Tertiary time upon a sheet of sand and gravel that spread over early Tertiary coal-bearing formations which in turn were laid down over folded schist. Prior to the deposition of the uppermost sheet, both the coal bearing formation (poorly consolidated sands, gravels, clays and coals) and the underlying schist bedrock were further deformed into a series of east west folds. The sheet, known as the "Nenana gravel" was a piedmont alluvial plain (as such structures are called) extending northward out from the Alaska Range, and covering the folded schist and coal-bearing formations. The streams flowing across the Nenana gravel piedmont were next rejuvenated and began down-cutting. Where the streams encountered or were superposed upon the coal-bearing formations (soft) they excavated broad valleys; but where they encountered hard schist ridges, they formed narrow canyons. Some fine examples of incised meanders are to be seen in the superimposed streams where they cross the hard schist ridges. Incised meanders are meanders cut deep into hard rock, and usually indicate inheritance of a drainage pattern developed on a former flat surface of unconsolidated material, such as the Nenana Gravel sheet that covered the area in Tertiary time.

The interruption of the cycle, which ultimately caused the non-adjusted drainage was the uplift in the Alaska Range that caused the Nenana Gravels to cover the foothills. Given sufficient time, without uplift, the drainage will again become adjusted to the structure.

Another type, somewhat similar to superposed drainage, is antecedent drainage. Antecedent drainage is that which has maintained itself across an area being uplifted; the drainage antedates the structure.

Of course, many other types of interruptions can cause non-adjusted drainage; climatic changes can initiate wind deposition or glaciation, either of which may disrupt existing drainage patterns.

DRAINAGE PATTERNS IN MOUNTAINS - The fluvial cycle in mountains, either fold or fault mountains, produces some characteristic drainage patterns. Fold mountain drainage patterns are well illustrated in the Appalachians, but may be observed in many other areas. The master streams of the Appalachians cut across the mountains at right angles to the folds and flow into the sea. These streams may have formed as consequent streams upon the folds or they may be antecedent or superposed from a previous drainage pattern. At first, longitudinal consequent streams flowed along the synclines into the streams draining across the folds. Into these synclinal streams, consequent streams flowed down the slopes of the synclines. As these streams cut into the anticlines, they eroded rapidly, because of the higher position of the anticlines. As softer rocks were uncovered inside the anticlines, they were attacked even more vigorously; and streams developed which ran lengthwise in the anticlines. These streams are subsequent streams, and the anticlines with their cores exposed, are said to be breached. (These streams are developed subsequent to the streams that are consequent on the initial slopes). It seems to be a common feature of fold mountains for the anticlines to be worn down to valleys and the synclines left elevated as ridges between the valleys. One explanation is that synclines may be inherently stronger than anticlines, because synclines are formed in regions of compression and anticlines in regions of tension.

Short tributary streams that develop at right angles to the subsequents are called obsequent streams (these flow down the sides of breached anticlines). Short tributary streams that flow down the sides of synclines are resequent (from recent and consequent).

The point at which a stream breaks through a resistant ridge is called a water gap; the notch which is left in the ridge if water no longer flows through a water gap is known as a wind gap. Wind gaps are to be found in all types of mountains, although care must be exercised so that they are not confused with ordinary passes.

The master streams in a folded region usually flow partly longitudinally and partly transversely to the folding. Their tributaries also flow either longitudinally or transversely, very seldom obliquely. This tendency leads to the development of trellis drainage, which is therefore characteristic of fold mountains.

Block mountains such as the Sierra Nevadas, formed by faulting, exhibit a different type of drainage pattern. Streams which flowed transversely to the faults have their courses either greatly increased or decreased in grade, depending on the direction of their courses in relation to the tilting of the blocks. Those with greatly increased grade tend to erode faster than their tributaries; the tributaries enter by rapids or gorges. The scarp faces in block mountains, of course, are immediately attacked by erosion, forming gullies that quickly develop into steep streams. The portions of the scarp between the streams often are triangular facets.

Continued erosion removes the facets, but if there is renewed uplift along the fault, the lower ends of the streams cut gorges, renewing the triangular facets between them.

A fault often brings into contact rocks of different degrees of resistance to erosion. When this happens, it is not unusual for differential erosion to cut down one side of the fault faster than the other. This weathering process may reverse the original relationship, leaving the up-thrown side lower than the downthrown. The drop off formed in this way is known as a fault-line scarp, and may migrate a considerable distance from the original fault.

In complex mountains such as those in Alaska, formed as they were by faulting, folding, and thrusting, the relatively simple drainage of less complex mountains is not seen. The drainage appears to be randomly developed, and often exhibits a dendritic pattern. In detail, however, the drainage in restricted localities usually conforms to structure.

Lakes And Swamps

Lakes and swamps occupy basins of interior drainage. All the forces of erosion are combined to fill in the lake with sediments on one hand, and to drain it by downcutting of nearby streams on the other; therefore they are of transitory existence. Nevertheless, lakes and swamps are very widespread, their existence indicating an interruption of the fluvial cycle, which has not been overcome by further erosion.

Consequent lakes are those left in irregularities on the sea bottom, as the land rises to form a coastal plain. Other lakes are formed by crustal movements, either downwarping or faulting. Some of these are formed in earthquake rifts or in the depressions caused by downfaulting of blocks (grabens). Others are formed by tilting in a direction against the regional drainage, causing streams to back up, much as does a man-made dam. Others are formed directly by the downbending of the crust to form a basin.

Stream action is responsible for many lakes, such as the oxbow lakes already discussed. Heavily laden tributaries sometimes build alluvial deposits large enough to dam main streams, or the main stream dams the tributary with a bar. The plunge pools at the bases of waterfalls are sometimes left as lakes, after the waterfalls causing them have become extinct. A few lakes may have been formed by streams quarrying out basins in jointed rocks.

Many lakes near the sea result from embayments or arms being cut off from the ocean, by the building up of bars; some, formed when crustal warping cuts off an arm of the sea, properly belong to the class of lakes created by crustal disturbances.

Volcanic activity is responsible for many lakes, some due to lava flows damming established drainage, and some occupying the craters of dormant volcanoes.

Wind action forms some basins, but as this action occurs in dry countries, these basins usually do not contain any water. Wind cannot erode below the water table.

In areas of limestone, small lakes are formed in solution cavities. (See Processes and Surface Forms of Underground Solution Areas).

Landslides may cause lakes to form, either by damming streams or by causing small basins to be left in the hummocky surfaces they create. But, by far the greatest cause of lakes is glacial action, which scours out large and small basins in the land underlying the glacier or dam valleys and whole regions, with ice or drift (material deposited by the glacier). (See Processes and Surface Forms of Glaciation).

Many lakes have become smaller or have vanished completely in recent times, but they always leave behind evidence of their former existence. This evidence is of many kinds. Lake-shore terraces are old shore or strand lines cut by waves at the level of the former lake's surface. The bed of a former lake usually is flat, and is built up of typical lake deposits, sand and silt which has settled out of suspension. These deposits usually are varved; that is, beds of relatively fine and relatively coarse material alternate. Varving is due to the fact that in summer the deposited material is coarser and more plentiful than in the winter. Individual beds are called varves.

PROCESSES AND SURFACE FORMS OF COLD LANDS, THE FLUVIAL CYCLE MODIFIED BY A COLD CLIMATE

Under mass wasting, mention was made of a process called solifluction, in which saturated material flows slowly down slope. Solifluction is particularly active in regions of permafrost, where a saturated, thawed layer develops each summer. This phenomenon is only one of several related ones observed in areas of cold climate; for instance, wind erosion and deposition is more important in cold regions than in humid ones. In many regions in high latitudes or high altitudes, the surface expression is so dependent on processes connected with permafrost or frost actions that some authors indicate a separate frost cycle or periglacial cycle. (Periglacial means, literally, the area adjacent to glacial ice, but is applied to any area having a cold climate, whether in the arctic or in high latitudes in temperate regions). However, the cold climate usually only modifies the landscape created by running water, or running water creates distinctive forms in permafrost areas, just as it creates distinctive forms in, for example,

areas of sedimentary rocks. For these reasons it is considered here only a modifying element in the fluvial process.

Permafrost Zones

Permafrost, as defined by Muller, is "a thickness of soil or other superficial deposit, or even of bedrock, at a variable depth beneath the surface of the earth, in which a temperature below freezing has existed continually for a long time (from two to tens of thousands of years)".

Students of permafrost find a continuous zone, in which there is very little thawed ground in Alaska north of the Brooks Range, a discontinuous zone, extending from the Brooks Range to the Alaskan Range, and a sporadic zone, in which isolated patches of permafrost occur. In Alaska, the sporadic zone occurs between the Alaska Range and a line which is slightly inland from the southern coast, and which corresponds roughly to a line drawn through points having a mean annual temperature of 32°F. Fig. 6-6 shows these zones.

Permafrost

In the discontinuous and sporadic zones, if the protecting cover of vegetation is removed, the upper surface of permafrost (the permafrost table) recedes. Therefore, it is inferred that permafrost in these zones is a relic of a former colder climate (Pleistocene time) and that the permafrost has been preserved by insulation from the sun's rays. In the colder parts of the discontinuous zone, permafrost is actually spreading. This may occur for different reasons. River bars, frozen in the winter may be covered by alluvium so fast in the next spring, that they have no chance to thaw, and consequently become permanently frozen. Again, permafrost may increase because of the differential insulating value of vegetation in summer and in winter. Winter cold can easily penetrate ground with little snow cover, even if the ground is covered with moss or tundra. On the other hand, summer warmth is less effective in thawing the ground thus frozen, because the dry, thawed moss cover of summer is a much better insulator than the frozen moss cover of winter. (The ratio of insulating values is about four to one).

When speaking of permafrost, degradation means its receding or thawing, and aggradation, its growth; (cf. the fluvial cycle). Generally speaking, permafrost occurs near the surface of the ground. In the sporadic and discontinuous zones, its upper surface may be from a few feet to several feet below the surface, and its lower surface at any depth down to three hundred feet or more. In the continuous zone it has been found as deep as two thousand feet.

Permafrost is frozen ground; it is independent of ground or rock composition. The ground near the surface which thaws each summer and refreezes each winter, is called the active zone. (In the winter the frozen ground of this zone is called the seasonal frost or winter frost.) Permanently thawed ground in an otherwise frozen zone is called talik, although usually it is referred to by prospectors as a simply thawed ground or a thawed streak. (It would more correctly be called unfrozen ground.) Frozen ground that contains no ice is called dry permafrost. It is fairly easy to dig, and does not decrease in volume appreciably when it thaws. It owes its lack of water to being relatively coarse and permeable. Fig. 6-7 shows some of the features found in permafrost areas.

Ground Ice

Most permafrost, however, contains ice (ground ice), which may occur as disseminated grains, lenses, vertical or inclined wedges, or irregularly shaped bodies. This ground ice forms in three ways: 1) A small percentage is simply buried winter ice that has formed in streams, ponds, or by percolating ground water. In the spring, the ice is buried beneath material transported during the spring thaw. 2) The second, which is the origin of the large masses, is by accumulation in frost cracks. In winter the ground freezes and contracts, forming cracks that often are arranged in polygons. Hoarfrost accumulates in the cracks during the winter, and in spring, water runs in, to freeze and keep the cracks from closing again in the summer. The next winter the process is repeated; contraction causes a crack to develop in the ice, in the ground, or between the ice and the ground; this crack is filled with ice. In this way the crack grows in thickness and assumes the shape of a wedge (ice wedge), pointed end down. The wedges often are inclined from the vertical, and may grow into irregular shapes, which, however, can always be recognized as having the wedge origin. Fig. 6-8 shows an ice wedge. Ice wedges often are arranged in adjacent polygons, each polygon forming a "cell." (See Fig. 6-9). If the surface of the soil in the center of the cell is higher than the surface of the ice in the surrounding polygon, the feature is called a high center frost wedge polygon. If lower, the feature is called a low center frost wedge polygon. High center frost wedge polygons form because of melting of the upper ice in the wedges, which leaves the soil higher than the ice surface. 3) Another origin of ground ice is by growth in place. It has been shown experimentally that water in minute spaces, such as exists in silt or clay, remains unfrozen at several degrees below its normal freezing temperature. This fact, coupled with the

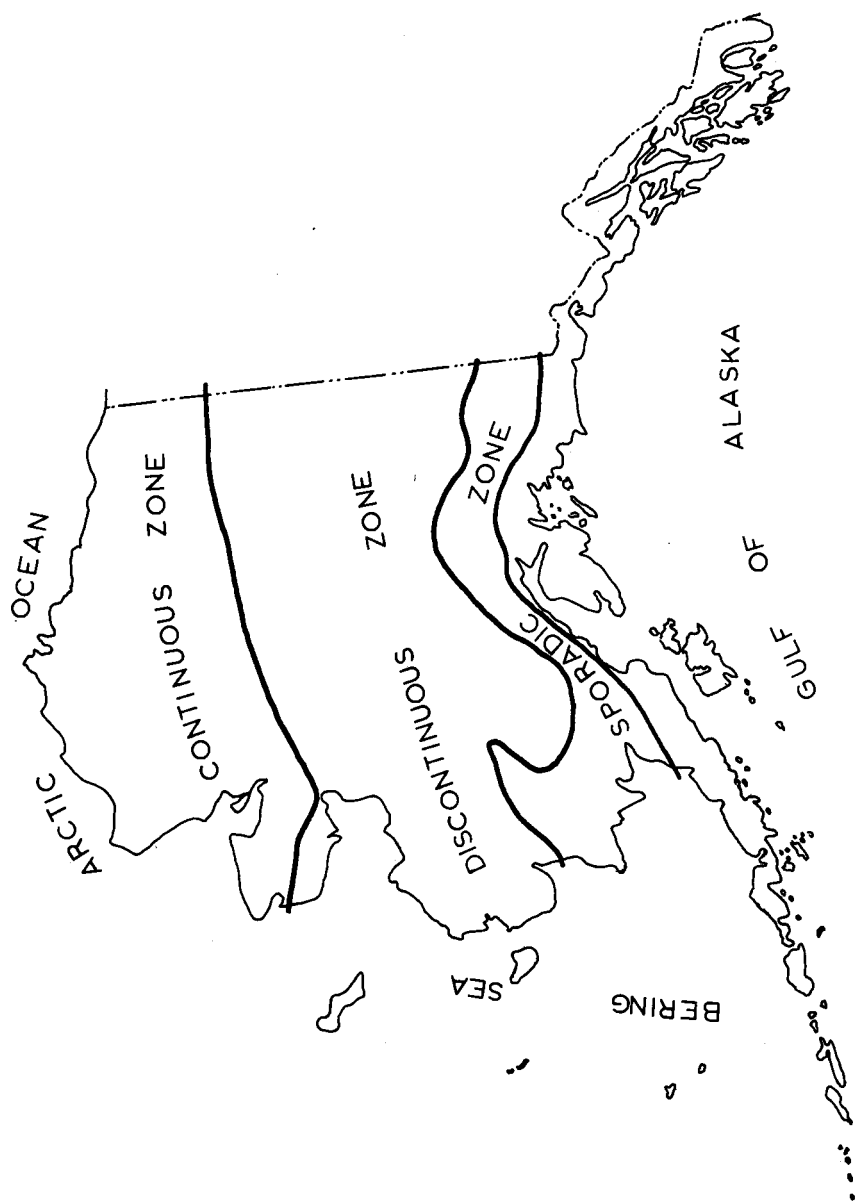


Fig. 6-6. - Permafrost Zones of Alaska

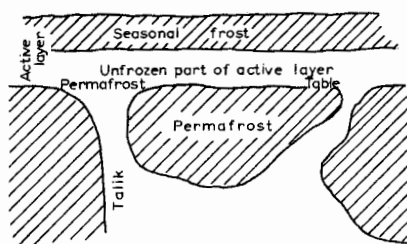


Fig. 6-7. - Features of Permafrost

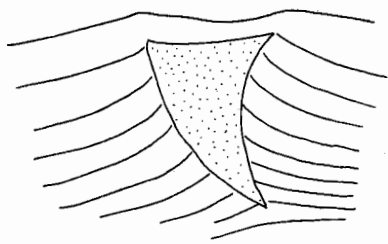


Fig. 6-8. - Ice Wedge, Showing Disruption of Bedding in Soil.

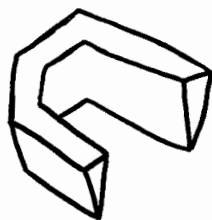


Fig. 6-9. - Ice Wedge Polygon Cells. Cutaway Single Cell on Left. Several Cells on Right.

physical phenomenon called "capillary attraction" which draws liquid through tiny spaces by surface tension force, makes it possible for water to move through frozen or freezing ground. This water provides a continual source of material which grows by crystallization into an ice mass. Ground ice formed in place usually occurs as thin lenses or disseminated grains. Although individual ice masses are small, this type of ice makes up an appreciable proportion of ground ice. Ice formed in this way is responsible for "frost heaving" in seasonally frozen ground. The ground ice formed by freezing in tension cracks (ice wedges) occur usually in fine grained, poorly drained ground, but may occur in gravel or sand, or even soft bedrock. The ground ice formed by growth in place can occur only in fine material, such as clay or silt.

There are at present no names by which ground ice of ice wedge origin and that which grows in place may be differentiated. It has been suggested that the first be called "Leffingwell Ice" and the second "Taber Ice," after the men who first described their origins. (See bibliography at end of chapter).

Thermokarst Topography

A region exhibiting surface features due to thawing of ground, is said to have thermokarst topography - an excellent descriptive name (karst topography is that formed by the slumping of ground above limestone which is being removed in solution by percolating ground water). The addition of "thermo" (heat) to "karst" describes the topography developed. Some of the features which collectively make up thermokarst topography are as follows. When stripping of the cover allows the ice in polygons to thaw, the spaces inside of the polygons are left as thermokarst mounds (an extreme form of high center ice wedge polygon). When large ice masses thaw, they leave holes called thermokarst pits, which are enlarged by further thawing and by percolating ground water. When ice wedge polygons thaw, drainage channels develop which more or less follow the angular pattern of the intersecting polygons. These channels become enlarged at the intersections, and develop into a connected series of enlargements. Such a drainage pattern is called beaded drainage. Cave-in lakes are lakes in basins, formed by the thawing of the ground ice. The waves lapping at their sides tend to enlarge them. The thaw-origin of such lakes is recognized by slumping sides, around which trees, if present, are leaning over the water. Cave-in lakes may become filled in by the encroachment of vegetation. Such lake bottoms are favorable sites for the growth of ground ice. This ground ice, in turn, may be thawed, and the dry lake bed incorporated into another expanding thaw lake. On the Arctic Coastal Plain of Alaska, the surface is continually planed as lake after lake forms, expands, and is filled in.

Solifluction

Solifluction, as a process of mass wasting, has been described and defined. Acting in conjunction with creep, solifluction accounts for most of the mass wasting above timberline in permafrost areas. The bedrock on the hills is broken by frost action first into large blocks, (large areas of these blocks are called *felsenmeer*). Mechanical disintegration into smaller fragments is effected almost entirely by frost action. Thus the preparation of material for mass movement in cold climates is entirely mechanical. Compared with other means of mass wasting, solifluction is rapid. Often it supplies material to the valleys faster than the streams can remove it; and in places the stream is squeezed together into a narrow, deep channel, by material flowing in from both sides of a valley. Here the unconsolidated material builds up in the valleys, freezing as it builds up, and the land gradually is reduced in relief. Fig. 6-10 shows material moving downslope by solifluction.



Fig. 6-10 - Solifluction- Steese Highway

The universal characteristic of surface expression in the Arctic is the tendency for smooth gradual slopes and rounded convex hills to develop. The development of this topography, approaching flatness by solifluction and the jumbled unsorted character of the material are definite and easily recognizable.

Muck and Silt

Muck is the term applied to fine grained silt in which is incorporated plant and animal remains. It is found in creek valleys and usually is permanently frozen. Most of the fine material in the muck is derived from windblown silt, known as loess, which during glacial times, was deposited as a great blanket over Interior Alaska. This dust was blown from the bars of streams draining the glaciers, which supplied vast quantities of finely ground silt; the thickness of this silt cover decreased with distance from the glaciers. The silt was easily eroded, and in the creek valleys it was carried away. However, the silt from the hills has constantly been transported by gullying, slope wash, and solifluction, into the creek valleys, incorporating with it veg-

etable and animal remains, to become muck. Muck and silt may be differentiated in several ways: muck is black, contains vegetation and has a fetid odor; silt is tan, odorless, and contains little vegetation. Inasmuch as it froze as it was deposited, the vegetation and animal remains were preserved. Muck in low ground, being poorly drained, is very favorable material for the formation of ground ice. The windblown silt which still remains in the uplands, on the other hand, contains little ice or vegetation. The silt is usually tan to grayish in color, the muck, black.

There are, without doubt, areas in glaciated regions where silt and muck have a different origin from that outlined above, in that they were deposited as lake deposits, which have since been exposed by drainage of lakes.

Altiplanation Terraces

In country undergoing solifluction, sometimes the summits and passes are flat, and the spurs descend in terraces. These phenomena are *altiplanation terraces*; they appear to be forming today above 4000 feet elevation in many parts of Alaska. Altiplanation terraces were named and first described by Henry M. Eakin of the U. S. Geological Survey, who also advanced a possible explanation for their formation. (See bibliography).

Patterned Ground

Patterned Ground is a term applied to ground in cold regions that exhibits various more or less regular patterns. Several explanations are given to account for each pattern, and it is probable that no one explanation can account for all occurrences of any particular pattern. The patterns fall into two general classes, those on level ground and those on sloping ground. The following classification is that of A. L. Washburne.

HORIZONTAL GROUND PATTERNS - On horizontal ground, the patterns are either sorted or nonsorted circles, or sorted or nonsorted polygons. (Note that these polygons are entirely unrelated to ice wedge polygons). The circles are spots, from one to several feet in diameter, of fine material that appears to boil up from below. The nonsorted type may contain rocks distributed throughout the fines; in other words, there is no sorting of coarse material from the fine. The sorted circles consist of a circular area of fine material surrounded by coarser material (rocks). The polygons are similar to the circles, except that the boundaries are polygons. Among the theories proposed to explain these phenomena are movement by alternate freezing and thawing, squeezing up of clayey material by the pressure generated during freezing in the fall, and differential weathering.

SLOPING GROUND PATTERNS - Patterns on sloping ground include sorted stripes and nonsorted stripes. Sorted stripes are stripes of alternating coarse and fine material, and nonsorted stripes are stripes of alternating bare and vegetation-covered ground. These stripes are thought to be horizontal ground patterns that have been elongated downslope by solifluction.

Icings and Related Features

The flow of water down a slope or stream valley does not stop as soon as the ground begins to freeze in the fall. In many places the water flows all winter, but as freezing progresses from the surface downward, the space available for the water becomes more and more constricted. If the space becomes too constricted, the water finds an outlet to the surface, where it builds up as ice. These ice accumulations are incorrectly called "glaciers" by many prospectors; the simple term *icing* is acceptable.

Such water forced out onto the ice of a lake or river is termed an *overflow*, and the resulting ice is called *overflow ice*. When it builds up in a stream valley, it is called *aufeis*. Places in a stream valley where *aufeis* occurs generally are places where permafrost is close to the surface, so that seasonal frost freezes down to merge with the permafrost. In the spring the thick accumulation of *aufeis* may force the stream against its bank, widening the stream channel by lateral cutting, and thus make available a wider area for further ice accumulation. The process ceases when the valley is wide enough to contain the ice in a thin layer which does not interfere with the flow of water in the spring.

The water between the seasonal frost and the permafrost may be under considerable hydrostatic pressure. This pressure, plus pressure exerted by crystallizing ice as it freezes, sometimes forces the ground above into a *frost mound*. Later, the mound ruptures, allowing any unfrozen water inside to be expelled. A *pingo*, a special form of frost mound, frequently attains a large size and lasts for many years. In many places, instead of the ground being arched up, a large mound-shaped icing forms, fed by water in the same manner as the frost mound. In Siberia, such *icing mounds* are known to develop enough hydrostatic pressure within themselves to explode, after which water rushes out for a short time.

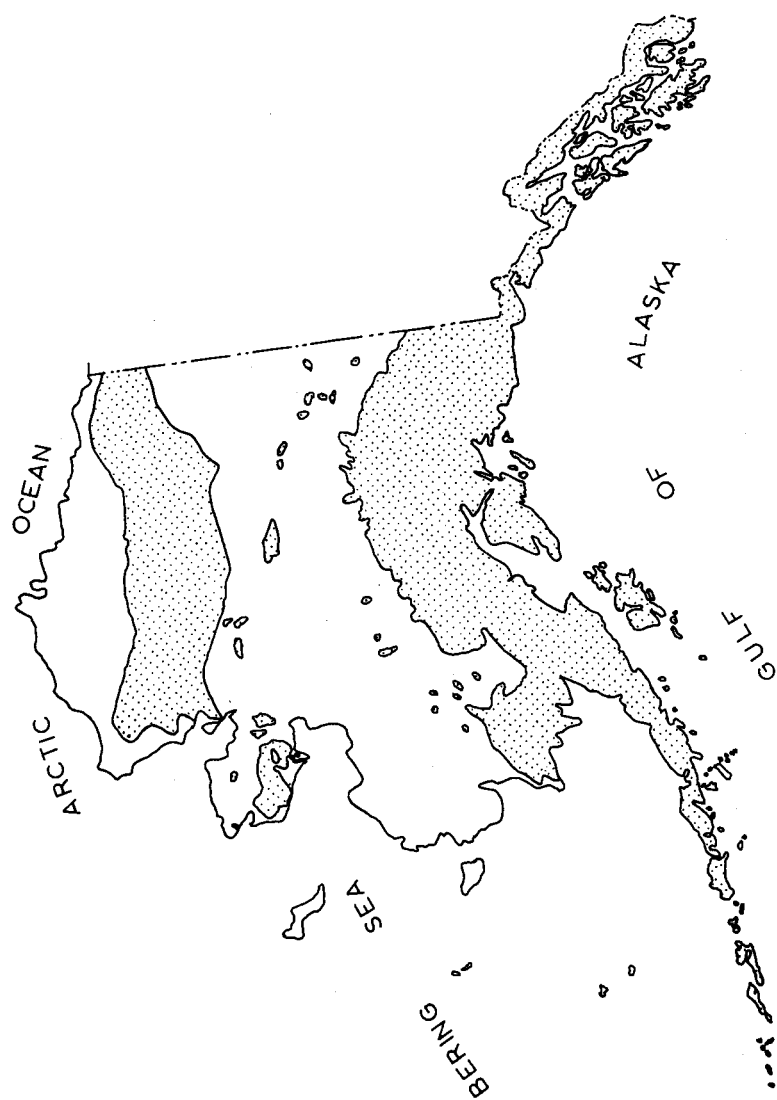


Fig. 6-11- Approximate Extent of Pleistocene Glaciation (Stippled) in Alaska. After U. S. Geological Survey

PROCESSES AND SURFACE FORMS OF GLACIATED REGIONS

In Chapter 5, it was shown that the earth is just emerging from a series of four glacial epochs, or is in the beginning of an interglacial epoch. As would be expected, therefore, large areas of the earth show effects of glaciation, and in glaciated regions, features left by the passage of the ice and by its melting are among the most important in the landscape. Glaciation refers to those changes of the surface, both erosional and depositional, caused by glacial ice. Glaciology is the study of glacial ice, its origin, the mechanics of glacial flow, and other subjects directly related to the ice itself. Glacial geology is that branch of geology which deals with glaciers and the effects of glaciation, with emphasis on the latter.

Recognition of the former existence of glaciers is very important, especially to the placer prospector. In Alaska, as in some other places, the ice originated in the mountain ranges and flowed both ways from the crests, covering an irregularly shaped area. Much of the Interior between the Brooks Range and the Alaska Range was unglaciated except locally. Also, some high ground within the glaciated areas, including many creeks, was left untouched. (See Fig. 6-11).

Glaciers are of two main types: valley glaciers and ice sheets. Valley glaciers are also called mountain, local, or alpine glaciers, because they are extensively developed in the Alps. Ice sheets commonly are referred to as continental glaciers, because usually ice sheets occur as glaciers of continental proportions. A third type of glacier—a combination of the two above, is called a piedmont glacier, and is formed by the coalescing of several valley glaciers to form a broad glacier covering the slope down which the valley glaciers are advancing.

This section is chiefly concerned with the effects of former glaciation upon topography (glacial geology), but to understand these effects, the prospector must understand the behavior of glaciers themselves, and have some knowledge about the existent valley glaciers still common in the Alaska Range and the Coast Mountains.

Glaciation is brought on by one or both of two factors: lowering of temperature and increase of precipitation. Temperature decreases with elevation and latitude; consequently glaciers tend to form in mountainous areas and in high latitudes.



Fig. 6-12 - Glaciated, U-Shaped Valley in Alaska Range

When the mean temperature drops to such a level that all of the snow that fell the previous winter does not melt in the summer, snow begins to accumulate. By thawing and aging, it becomes granular and massive, then with or without burial under new snow, it compacts into ice. The granular snow is called *nev'e* (nayvay).

Valley Glaciers

In Alaska, valley glaciation is more important than continental glaciation. In the higher parts of mountains there may be an area of perpetual snow, called a snowfield, in which ice is formed by compaction, as explained above. As pressure increases due to the weight of overlying snow and ice, the ice begins to flow as a plastic, and descends in previously existing valleys, which then become glacial troughs. If the ice accumulates in the snowfield faster than it melts or breaks in the area of wastage at the lower end, the glacier continues to advance down its channel. Usually, however, the rates of accumulation and wastage reach equilibrium, and although the glacier continues to flow, the end does not advance. When wastage exceeds accumulation, the glacier melts back. Where the gradient of the glacier is increased due to irregularities of the valley bottom, transverse tension cracks - called crevasses (*kre-vah-ses*) develop at the surface. Crevasses also form on the edges, making a 45° angle with the sides, in an up-valley direction. Where a glacier emerges from a constriction, parallel longitudinal cracks develop. Glaciers waste by melting and by breaking off into the sea. This breaking off is called calving, and the calves float away as icebergs.

Valley glaciers erode principally by scouring with the rocks frozen into their undersides and by plucking or quarrying chunks of bedrock. The scouring of bedrock produces glacial striations oriented in the direction of latest flow. Chatter marks are dents or grooved scratches, sometimes convex in the direction from which the ice came. A *roche moutonnée* (sheep rock) is a knob of rock, scratched or smooth, and tapered on the end from which the ice moved, and rough and steep in the direction of movement. This characteristic is due to the fact that scouring is the eroding force on the "upstream" side, and plucking on the "downstream" side. *Roches moutonnées* are found wherever glaciers existed.

Glaciers do most of their eroding in the middle and upper reaches, because the ice is thicker there, exerting a greater pressure. Therefore, the long profile of a valley after a glacier has flowed through it for some time, has a fairly flat grade, abruptly steepening at the head. The scouring in the middle reaches may actually be intense enough to cause bedrock in the middle of the course to be lower than that farther downstream, forming a bedrock basin.

The sides of a glacier-occupied valley are sheared off, leaving steep valley walls which truncate the spurs between the tributaries. Another mark of a glaciated valley is the "U-shaped" cross section cut by the ice, due to the ice occupying a much larger part of the valley than does water. (See Fig. 6-12). If the valley contains much alluvial fill, the bottom of the U-section is covered and not visible. The erosive ability of a glacier is dependent upon its size, and the larger glaciers occupy larger valleys, consequently the large valleys are cut down faster than their tributaries which contain small glaciers or none at all. Because of this difference in rate of cutting, the tributaries enter the main valleys at a higher level (a discordant junction which is rare in a landscape formed by the fluvial process). Such higher valleys are called hanging valleys.

Valley glaciers head in amphitheater-like bowls called cirques (*serks*). Cirques are usually deeper in the centers than at the rims, forming basins. The power which excavates this basin is supplied by the abrading action of the ice, and by the snowfield at the head of the glacier alternately thawing and freezing. Expansion and contraction during the freeze-thaw cycle causes spalling and ice wedging of chips of rock. (Spalling is chipping by unequal expansion; ice wedging by the expansion which accompanies the freezing of water). Cirques containing glaciers with no valley glacier attached are called hanging cirques and contain cirque glaciers. Beyond the outer edge of a cirque is a sharp drop off called the valley headwall; if the valley develops a glacier, this drop off becomes a trough headwall. If a cirque is free of ice, a lake called a tarn, may form in its basin. Fig. 6-13 shows a tarn in a cirque.

The floors of many glacial troughs are not evenly graded, but contain basins, below which are bedrock barriers. The valley floor thus resembles a flight of steps with long, hollowed-out treads and low risers. The bedrock barriers, which drop off in a down-valley direction to the next basin, are called *riegels*. They usually have a notch or gorge cut into them by post glacial stream erosion. The basins often contain lakes, which, when strung out like beads, are called paternoster lakes. Many theories attempt to account for the formation of the steps; probably a combination of the original configuration of the stream-cut valley, bedrock structure, and differential erosive power of the ice is responsible.

Cirque growth and valley glaciation produce some distinctive forms, first described and named in the Alps; an area containing these forms exhibits alpine topography. If at an early stage in alpine glaciation, several cirques take round "bites" out of the mountainsides, they produce a fretted upland, or biscuit board topography, indicating youth in

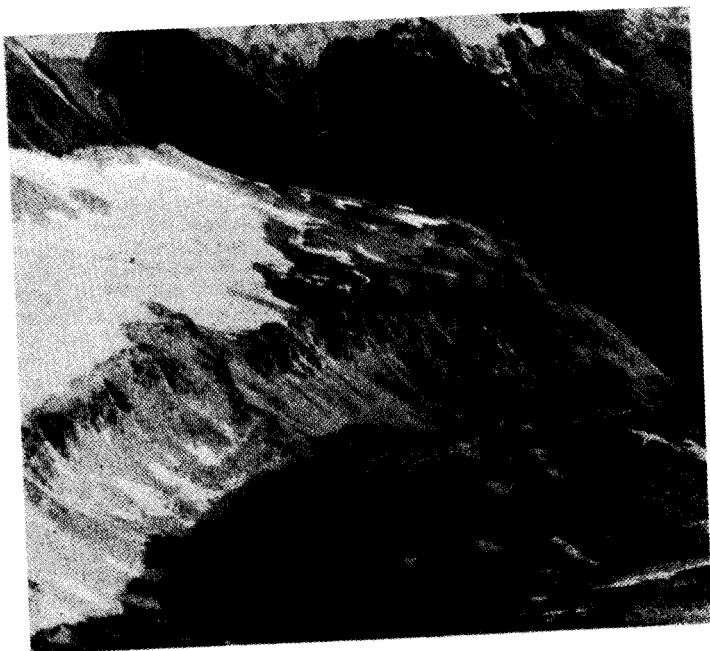


Fig. 6-13 - Tarn, Alaska Range



Fig. 6-14 - Horns and Knife Edges Being Formed by Cirque Glaciers, Alaska Range.

the glacial cycle. Two cirques growing headward towards each other from opposite sides of a divide, produce a notch called a glacial col, distinguished from a col produced between two streams by the fluvial process. The divide between the two cirques is sharper than between two streams, because cirques have steep blunt headwalls, and the ridge developed along the divide between two ice drainage areas is a knife edge, or as named in the Alps, an *arête*. Cirques growing headward around a domed or volcanic mountain (in a radial pattern) finally produce a sharp peak called a horn. An isolated peak jutting above a snowfield or a glacier is called a nunatak. Fig. 6-14 shows horns and knife edges being formed.

A geomorphic cycle of valley glaciation is conceived by some but it is not accepted by all authorities. The cycle is initiated, as are all cycles, by an interruption; in this case, a climate change toward a colder temperature or greater snowfall, or both. Cirques are formed in pre-existing hollows, and begin to grow in the stage of youth. Fretted uplands, horns, and cols, are evidences of youth to maturity. In maturity, all of the trunk valleys are occupied by valley glaciers, with numerous tributaries. At this stage also, the uplands are covered by snowfields surrounding nunataks. Perhaps, also, the valley steps are eliminated by glacial scouring, and the trough headwall overtakes and merges with the cirque headwall in maturity. The reduction to a region of low relief, corresponding to a peneplane, has never been observed. One explanation for this phenomenon is that with reduction in elevation come warmer temperatures.

The sea is not the ultimate base level of erosion by glacial action. Ice will not float until nine tenths of its volume is under water, so a thick glacier effectively erodes the sea bottom after it reaches the coast. The scoured-out seaward ends of some glaciated valleys attest to this fact. The lower parts of such valleys, now occupied by arms of the sea are called fiords. The seaward ends of fiords are shallower than those parts farther inland, probably for the same reason that basins form in glaciated valley floors. Fiords which occur on many high coasts which have been glaciated, are beautifully developed in Southeastern Alaska.

A glacier moving down a valley accumulates rocks and dirt, which fall upon the sides of the ice or are plucked from the valley walls. This accumulation is called a lateral moraine, and when two glaciers flow together, forming one glacier, the inside lateral moraines coalesce to form a medial moraine down the center of the glacier. Medial moraines are not confined to the surface of the ice but extend to the bottom. Fig. 6-15 shows valley glaciers, with lateral and medial moraines.



Fig. 6-15 - Valley Glacier - Alaska Range

The front of an advancing glacier acts like a plow, pushing before it a front of piled up rocks and dirt. When the glacier finally stops its advance, this material is left piled up as a push moraine. An end moraine is one built up of the material in the glacier (englacial material) as it melts at its terminus.

Glaciology and Erosional Features of Continental Glaciers

When combined cold temperature and high precipitation become intense enough to cause ice to accumulate at altitudes and latitudes lower than those in which alpine glaciation takes place, the conditions are favorable for continental glaciation by ice sheets. This process starts at some center, or centers, of ice accumulation and the ice spreads in all directions. Two continental glaciers are in existence today: on Greenland and on Antarctica; but at one time or another during the Pleistocene ice ages, ice sheets covered most of North America down to a line roughly corresponding to the present courses of the Ohio and Missouri Rivers. Much of Europe was similarly covered. The western part of North America including the Rockies and Coast Ranges, from Washington and Idaho north, was occupied by valley and piedmont glaciers. Only two extensive unglaciated areas occur in the entire northern part of the continent. These are in that part of Alaska (and adjacent parts of Canada) between the foothills of the Brooks Range and the Alaska Range, and 2, the Arctic slope of Alaska. As it is assumed that the temperature was cold enough for glaciation, this lack of glaciation must have been due to scanty snowfall.

Because there is little movement of the ice over the ground in the main body of the glacier, ice sheets do most of their erosive work near their margins. Scouring, plucking, and quarrying thus occur at the edges of the glacier. As the glacier advances, this area in which erosion is active also advances. The grinding produces large amounts of rock flour, finely ground rock which, when suspended in water, is called rock milk. Much of the loose overburden in the path of the glacier is pushed ahead to be deposited in various topographic forms; but bedrock does not undergo as much erosion as it does in the path of a valley glacier, except possibly where the ice is channeled into pre-existing valleys or troughs.

The really far reaching effects of continental glaciation upon the topography of a region are due to the drainage changes caused by rock quarrying and deposition of overburden. Almost all of Minnesota's "10,000 Lakes" are of glacial origin.

Piedmont Glaciers

Piedmont glaciers, formed by the coalescing of valley glaciers, behave much the same as do ice sheets, except that they do not advance far beyond the foothills of the mountains in which they form.

Depositional Features of Glaciers

All of the unconsolidated material that owes its origin to glaciation is called glacial drift because formerly it was thought to have been "drifted" into place by water. Drift is of two major kinds: that dumped by the glacier with little or no water stratification, and that deposited as glacial outwash by streams. Drift of the first sort is called till, and consists of material, from the finest particles to large boulders, all jumbled together with no stratification nor size sorting. Till is sometimes known by the less satisfactory term boulder clay, suggested by the usual occurrence of tiny clay particles and large boulders in the same deposit. It is easily recognized, but the prospector should be careful not to confuse it with the products of soil creep or solifluction, which also produces nonsorted deposits. Distinction can be made by the presence of striated rocks and erratics in the till. (An erratic is a rock from outside the drainage area, which could only have been brought to its resting place by the ice). Till is the material of moraines, and may be of two types: basal, or that deposited under the glacier, or supraglacial (above the glacier), which is let down from the top of the glacier by the ice melting. Basal till generally contains more clay and other fine material than does supraglacial till.

FEATURES OF TILL - Some of the till features associated with valley glaciers have already been mentioned, i.e., end or terminal moraines, lateral and medial moraines. Terminal moraines, formed where the terminus of a glacier was stationary for some time, also occur around the margins of ice sheets or piedmont glaciers. Ground moraine is a cover of material which accumulates on the ground after the melting of a glacier. It is generally thin in relation to its areal extent and has a rolling, irregular surface. In places it is hundreds of feet thick; in other places it is so thin that the topography reflects the underlying bedrock or other deposits.

A kettle is a small closed basin, often containing a lake, formed by the melting of a block of ice which was surrounded by drift. Many till-covered areas, when viewed as a whole, exhibit a rough surface, a combination of an irregular ground moraine surface and numerous kettles. This rough surface is called knob and kettle topography. (See Fig. 6-16).



Fig. 6-16 - Snow Covered Knob and Kettle Topography - Alaska Range

Erratic boulders, some larger than an ordinary house, sometimes dot the landscape. Perched boulders, rocks that have been let down by the melting of the ice onto a small hill, are unstable and eventually topple and slide down. Boulder trains, linear or fan shaped aggregations of rocks from a common source, are oriented in the direction of flow and may be hundreds of miles long. The fan shape probably is the result of a shift in direction of flow of the glacier. Drumlins are streamlined hills of till, with the blunter, steeper end (the stoss end) facing against the direction of ice flow, and the tapered end (the lee end) facing in the direction of flow. They are thought to be built up from till disseminated through the lower portions of the ice. They occur from New England to Wisconsin; so far as is known none occur in Alaska.

FEATURES OF STRATIFIED DRIFT - Drift of the second, or water laid sort is called stratified drift, washed drift, or glacio-fluvial deposits. This drift, by far the most abundant, is sometimes impossible to distinguish from other water-laid sediments. It occurs in several forms, and has a number of origins.

Such deposits are of two general types: the proglacial type, deposited by meltwater some distance away from the glacier; and the ice-contact type, deposited by water action in contact with ice. Proglacial deposits lose more and more of their glacial-origin characteristics with distance from the glacier.

Proglacial Features - Proglacial stratified drift is deposited in streams, in lakes, or in the sea. Stream-laid proglacial deposits are called outwash deposits and take the same form as those laid down by heavily loaded non-glacial streams, showing great variation in size of material vertically and horizontally (sorting). In the discussion of fluvial processes it was shown that a stream adjusts its gradient to that just necessary to transport its load. Therefore, a heavily loaded stream issuing from a glacier would be expected to have a steep gradient, which is true. Such streams are braided.

Outwash from ice sheets or piedmont glaciers may take the form of large fans or sheets called outwash fans. Outwash occupying a valley is called a valley train. When deposited, it is crowned, or has a slope from its center line towards its sides, although later, compaction may obliterate this feature. Such deposits may be terraced, because meltwater streams during later stages of melting may erode the central parts, leaving terraces along the sides. Pitted outwash is dotted with kettles left after melting of ice blocks partly or completely buried by outwash.

The second class of proglacial deposits is formed in lakes. During the ice age, many more lakes existed than do now, due to the temporary damming of streams by ice, till, and outwash. Some of these lakes formed where the ground sloped down to the ice edge - either in individual

valleys or over whole regions. Smaller and less common lakes were formed where streams were dammed by drift. Many old lake beds formerly covered by large lakes, occur north and west of the Great Lakes area; the present Great Lakes are shrunken remnants of such lakes.

In Alaska former glacial lakes are likely to be found in two main areas: in the glaciated regions of the Brooks Range, and in the coastal mountains and the Alaska Range. In Alaska many examples of tributary streams formerly dammed by ice flowing down the major river valleys are known. Because some of these creeks have produced gold, they have been closely studied; Nolan Creek in the Koyukuk district and Tobin Creek in the Chandalar district are two such streams. Lakes are also formed by the damming of a major stream by ice or outwash from a tributary valley.

The deposits in lakes of glacial origin are of four kinds: deltas, bottom deposits, shore features, and rafted erratics. In the section on the fluvial cycle, a few of the different features associated with lakes were mentioned, and those features, of course, occur in lakes of glacial or non-glacial origin, as do most of the following.

Delta deposits are formed where streams enter lakes; those formed by glacial streams do not differ from those formed by any other kind, except that they occasionally are continuations of eskers (to be defined shortly). Sand and gravel are the main constituents of deltas.

Lake bottom deposits are composed of finer material, silt and clay, which is carried in suspension farther from the shore. These deposits are likely to be better developed in glacial lakes than in other types of lakes because of the great amount of fine material produced by the abrasion of the glacier. Well developed varves are present in glacial lake deposits because of the seasonal melting and freezing of the glacier. Lake bottom sediments in the beds of the former large lakes connected with continental glaciation, in some places form flats, hundreds of miles across.

The most notable shore feature left behind as evidence of a former lake's presence, is the wave cut beach which has already been mentioned. These terraces are well developed around the Great Lakes at several different elevations. The main reason that they are cut at different levels is that the weight of the ice sheet depressed the earth's crust, and as the ice melted, the crust returned to its former level. This action raised the old beach lines to higher elevations and allowed new ones to be cut. Some beach lines at different elevations are due to draining of lakes in stages. Raised beach lines are poorly developed in Alaska because the small lakes formed by the streams, dammed by valley glaciers, were too short lived to have cut prominent beaches.

Rafted erratics, as their name implies, are erratic boulders rafted on ice into a lake, then dumped to come to rest among the lake bottom sediments. They generally occur in groups or "nests."

Marine deposits are similar to lake deposits, except that varves do not occur because clay in seawater flocculates and settles out at the same time as the silt.

Ice Contact Features - Ice contact stratified drift is, as its name implies, laid down next to the ice. It is distinguished from proglacial drift by an extreme range in grain size within short distances, by its close association with till, and by its deformation. Rushing torrents alternate with complete cessation of water action, the alternation resulting in differences in degree of sorting and stratification.

The surface of ice contact stratified drift tends to a rough appearance, with knobs and small closed basins, where ice melted away. (Because landslide areas exhibit much the same topography, caution must be exercised in the interpretation of such features). These ice contact deposits also may be formed by the melting of the terminal parts of a glacier, over which stratified drift has built up. The drift is let down onto the ground, exactly as is till in the formation of some types of moraines. The most distinctive forms of stratified drift are those of contact features, of which the following are the most important.

Kames are mounds of stratified drift formed by filling of holes or crevasses in the ice. They may be rounded or ridgelike, and occur in areas of valley or continental glaciation. A kame terrace is a terrace built between a glacier and the wall of the valley by a stream of melt-water. It differs from an ordinary terrace in that it is not part of a valley filling which once occupied the whole valley. The inner (ice contact) edge may have a rough surface, with kames and kettles. The terrace may be discontinuous where the depositing streams swung out onto the ice of the glacier. Kame terraces, of course, are connected only with valley glaciers.

Eskers are comparatively long sinuous ridges, which suggest the meanderings of a stream. They form under any type of glacier and tend to follow the direction of latest movement of ice sheets, sometimes following preexisting valleys, if such valleys happen to be more or less parallel to the direction of ice movement. Eskers, which vary from a few hundred feet to fifteen miles in length, are believed to have formed from till deposited as stratified drift by streams under the ice. Although most eskers were formed on edges of continental ice sheets, some are believed to be forming under piedmont and valley glaciers in Alaska today.

Practical Effect Of Glaciation On Prospecting

What do all the mechanisms of movement and features derived from glaciation mean to the

prospector? Over large areas of Canada, the continental ice sheet has removed much of the overburden, leaving fresh bedrock exposures. Thus, glaciation in Canada has been a help to lode prospecting.

The placer prospector, however, has not fared so well, and it is with placer prospecting that this discussion deals. When the continental ice sheet removed the overburden and opened up exposures for the lode prospectors, it removed any placers which might have been present. Perhaps the reason that lode mining developed south of the Alaska Range, and placer mining north of the Range, may be attributed to the glaciers removing the placers in the south, and at the same time exposing the bedrock. In the Interior of Alaska, the situation is reversed.

A few scattered diamonds have been found in glacial drift in Wisconsin, and much speculation has occurred as to their location before the ice pushed them from their water-laid resting place. This example illustrates that glaciated country presents serious problems in the search for placers. Yet many valuable placers have been found in glaciated areas of Alaska.

In the past, it has been recognized that some of the placers occurring in glaciated parts of Alaska were derived from reconcentration of gold by stream action subsequent to the retreat of glaciers; and it has been thought that elsewhere placers were formed during an interglacial time and, somehow, preserved from destruction by later erosion. The general idea of most prospectors, however, although at times only vaguely expressed, is that because a long period of weathering and water action is necessary for formation of placers, and that because glacial action removes and dissipates products of long continued water action, glaciated regions, consequently, are unsatisfactory places to search for placers. It is beginning to be recognized that this is not the whole story of the occurrence of placers in glaciated areas.

The effects of glaciation on placers in Alaska is a complex subject not very well understood. Detailed work by the U. S. Geological Survey upon the origin of placers in Alaska is now underway, and in the future, glacial effects will be much better understood, as will the formation of placers in general. Some of the possible relationships of placers to glaciation, so far as they are understood today, are discussed below.

In several places in Alaska, glaciation has been studied intensively enough so that more than one period of glaciation can be recognized. In those areas, the effects of the last advance are much in evidence, with obvious disruptions of stream channels, sheared valley walls, hanging valleys, and other features easily identified. The older advances, however, are represented by features that have been eroded to a greater or lesser extent, depending on their ages. Most of the material making up these older features (till and stratified drift) has been carried away and redistributed. From this it follows, that even if a placer existed early in the Ice Age, and was dissipated by an early glaciation, the chances are good that a new one could have been formed by a reworking of the glacial material. Furthermore, placers were formed throughout Quaternary time and it is possible, or rather probable, that placers of an area did not come into existence until after the earlier ice had been gone for a long time. However, if the placer existed toward the end of the ice age (as recently as a few thousand years ago in some places), and was destroyed by the last ice advance, chances that it could have been reconcentrated since the disappearance of the glacier are much less favorable (unless by meltwater in a very short time, as will be discussed later). Grossly simplified, if a placer existed 50,000 years ago, a glacial advance that occurred 75,000 years ago does not concern it, but an advance of 25,000 years ago may have scattered it. Studies at Nome indicate that some of the rich creek placers are outwash reconcentrations of early glaciation. Later glaciations, which occurred farther inland, did not extend far enough south to influence these placers. Even at Circle, where late glaciation has not been recognized, there is evidence that some of the placers are due to a reconcentration of earlier outwash deposits. From these facts, it is apparent that later glaciations hold the most interest for the placer prospector.

Obviously, if a glacier has moved down a stream that contained a placer and has scoured bedrock to form a U-shaped valley, the placer has been pushed out and scattered with the till. Part of it may be found in the end moraine, but this portion probably will not provide the basis for a large scale operation. If a prospector should find such an area of gold-bearing till, he would do well to mine by hand and not spend much time looking for more after it is exhausted.

Subsequent water action, either by recent streams or by meltwater, may reconcentrate gold that was pushed out by the ice. As large quantities of water are available during the melting of the glaciers, such reconcentration should be the rule rather than the exception, although not necessarily resulting in the formation of a commercial placer. Some of the placers of the Chisana, Valdez Creek, and Kantishna districts have been formed by reconcentration of till and glacial outwash deposits, partly by meltwater, and partly by later stream action.

Some of the meltwater reconcentrations of outwash and till have been in side glacial streams. Here, tremendous torrents of water flowed along the sides of glaciers, cutting deep channels in what may have been a matter of centuries or possibly just scores of years. Usually these channels were filled with later outwash or Recent deposits, as a Tammany Channel in the Valdez Creek district. Another example is the bench of Nolan Creek, in the Upper Koyukuk district near Wiseman. This bench was thought to be a beach deposit of a glacial lake, however, the presence of a bedrock rim between the high channel and the main stream makes it likely that

it is either a normal bench or one formed by a side glacial stream.

Deep channels, however, are not necessarily carved by side glacial streams. Hammond River, also in the upper Koyukuk district, has a channel one hundred feet deep, so narrow in places, that it is said it was difficult to turn a wheelbarrow around. Such a deep narrow channel could only have been cut when the local base level (the valley of the Koyukuk River into which Hammond River flows), was very low, and when large amounts of meltwater were available. These conditions would be fulfilled during melting of the glaciers. Hammond River contains placer deposits at three levels; in the deep channel, on a terrace at a depth of forty feet, and in the present creek where it flows on the left limit of bedrock. These deposits correspond to changes in the amount of water available and in base level, which in turn were dependent upon advances and retreats of the ice.

Most of the creeks entering the glaciated valleys of major streams in the Brooks Range contain deep, filled channels. Some of them may have the same origin as the Hammond River Channel - deep and rapid erosion during the melting of one or more ice invasions with subsequent filling in with sediment, perhaps derived from the melting of ice farther up in the mountains.

A placer deposit may survive subsequent glaciation in several ways. It is possible for ice to cross a creek at such an angle that bedrock concentrations are not disturbed. The bottoms of deep channels, such as that of Hammond River, would be almost immune from ice disturbance. Usually, however, when a placer exists in recently glaciated country, it can be demonstrated that ice did not reach the creek in which the placer is located.

Most of the placer districts of the Brooks and Alaskan Ranges are located near the outer fringes of glaciation, at least of the last glaciation. Here, ice of the latest glacial advance was confined to major river valleys, located generally at lower elevations than their gold-bearing tributaries. Examples are to be seen of placers in tributary streams unaffected by glacial ice that filled the main river valleys. Although glaciers sheared off the lower ends of the tributary streams and even forced lobes up into their mouths, the placers in the upper reaches are undisturbed. These tributary streams often were left as hanging valleys and now enter the main valleys through notches cut into the kame terraces along the margins of the valleys. Where such a situation exists, the placer deposit of the tributary stream is unlikely to extend into the glaciated valley, or even into the glacial deposits at its mouth. A good example of an unglaciated placer stream entering a large glaciated valley is Little Squaw Creek in the Chandalar District. See Fig. 6-17. Before the last glacial advance, Little Squaw Creek flowed into a large river. It cut through an area of extensive gold mineralization, hence contained a placer deposit. When the main river valley was filled with ice, the lower part of Little Squaw Creek was sheared off. Subsequently, ice in the main valley became stagnant and rotted away, leaving the lower end of the creek filled with glacial debris under which the pre-glacial channel extended for a short distance. The creek continued to erode mineralized bedrock, and an extension of its placer was built out over glacial deposits. The extension did not extend very far, however, because almost all the gold was coming down from bedrock sources upstream, and very little was available in glacial debris at the lower part of the creek. The paystreak, therefore, fanned out and ceased to exist. The distance that the preglacial placer deposit extends under glacial deposits is unknown, but it probably was sheared off a short distance downstream from where it crosses into the glacial deposits.

The great fluctuations in base level that sometimes accompany advances and retreats of the ice have been mentioned to partially explain the carving of deep channels in some streams during melting of the glaciers. Another result of these fluctuations is the carving of modern canyons in Recent (post glacial) times. A stream may develop a meandering pattern on a surface of till or outwash and be superposed upon bedrock ridges as the base level is lowered by erosion. Thus Valdez Creek, on the upper Susitna River, and Wiseman Creek, on upper Koyukuk

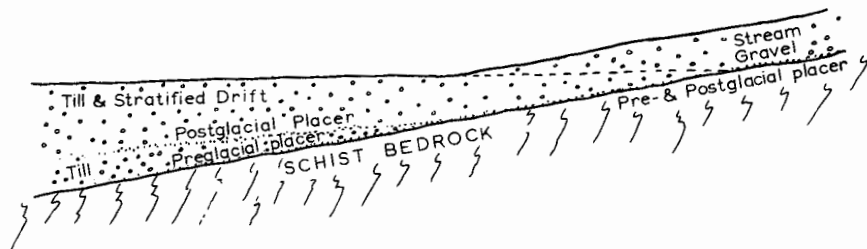


Fig. 6-17. - Generalized Relation of Placers to Glacial Deposits on Little Squaw Creek, Chandalar District, Alaska, Vertical Scale and Gradients Exaggerated

have both carved canyons since the retreat of the glaciers.

This brief discussion of glaciation and its effect upon placers is concluded by repeating that glaciation of a region does not necessarily mean there will be no commercial placers found. If the last ice advance did not touch the placer, a rich one may be found, formed during an inter-glacial period, or by reconcentration of gold in till and outwash during or since the last ice age. Many placer prospectors in the past have followed the axiom, "Stay away from glaciated country," but it is now known that it was the latest ice movement which caused most of the destruction and even post-glacial placers may be present. The recognition of the effects of this last ice advance is a primary concern of the placer prospector.

PROCESSES AND SURFACE FORMS OF ARID LANDS

Running water is the principal eroding agent in arid lands; but because it is less abundant and comes in infrequent floods, its effect is different from that in humid areas. In addition, wind is more active as an eroding agent in arid than in humid areas. For these reasons distinctive land forms are produced in arid regions.

An arid region is defined as one receiving less than ten inches of precipitation per year; a semi-arid region as one receiving ten to twenty inches per year. By this definition, much of Interior and Northern Alaska is arid or semi-arid. These relatively dry areas, however, exhibit characteristic forms of more humid areas because the rainfall is fairly evenly distributed, evaporation is slight because of the cool summer temperatures, and because underlying permafrost in some places prevents sub-surface drainage. In short, Interior and Northern Alaska have a "cold" climate rather than an arid one. Some features of the landscape of a country having a semi-arid climate are present in Alaska, however; for instance, sand dunes, loess deposits, and badlands topography.

Erosion By Water Under Arid Conditions

In arid regions, mechanical disintegration is more important than chemical weathering, although chemical weathering is extensive. There may or may not be a covering of sod; even where sod is present, the soil beneath is loose and dry, and susceptible to erosion if vegetation is removed. As the rainfall tends to come at infrequent intervals, although in torrential downpours, steep gullies are eroded. Much of the runoff in arid regions is by sheetflood, or a thin, spread-out system of tiny coalescing rills which continually change their paths. The total distance moved by the water is usually slight, a few miles at most, after which the water soaks into the ground.

A characteristic of warm arid regions is interior drainage, with the drainage of an area flowing into a closed basin from which it evaporates. During rains, water from hills or mountains rushes down deep narrow valleys called washes. Where the streams emerge from the hills, the grade abruptly flattens and large fans are built up, across which the water moves by sheetflood. Alluvial fans are most fully developed under arid conditions.

Badlands topography (deriving its name from the Badlands of South Dakota) form in poorly consolidated rocks or in unconsolidated mantle. Although badlands may form under humid conditions, they are most common in arid and semi-arid climates. The topography consists of steep, almost vertical walled gullies and pinnacles. Badlands are well developed in the poorly consolidated sandstones and conglomerates of the coal-bearing formation of the Bonfield district of Alaska.

The Wind As An Erosional Agent

The wind is an effective erosional agent even in humid regions, and it has been mentioned that wind erosion is important in cold regions. However, wind is most effective in dry countries. Like all other erosional agents, the wind erodes and deposits. Sand blasting by wind-driven sand helps in the disintegration of bedrock, and the removal of dust and sand by wind acting as a transporting agent is called deflation.

Some investigators believe that in different parts of the world, extensive plains called *boisson* plains have been cut into bedrock exclusively by the wind. These plains would be end products of the arid cycle, and the occasional mountain remnants, corresponding to monadnocks, are called *inselbergs* (German for island mountains).

In some areas the fines are blown away, leaving behind coarser material, which eventually accumulates as a residual product to cover the area and inhibit further erosion. This cover is known as lag gravel or desert pavement. Wind faceted rocks showing effects of sandblasting are called *ventifacts* (wind made).

The ultimate base level of erosion by wind is not sea level, but the water table. In places, deflation operates on the ground below sea level, but opinion is divided as to whether this result has been effected exclusively by wind action.

The two main kinds of wind deposits are dunes and loess deposits. Dunes form wherever sand

is available - near shores, outwash plains, river beds, inland deserts, or in any area where soft rocks are breaking down. Winds blowing from one direction produce two kinds of dunes. Moderate winds produce dunes having the appearance of ripples at right angles to the wind direction, called transverse dunes. Strong winds blowing from one direction produce longitudinal dunes, long strips of sand oriented lengthwise to the direction of the wind. Winds of intermediate strength produce dunes having characteristics of both types; among them is the barchan, a crescent shaped dune with its horns pointing downwind. Barchans have a gently sloping windward side and a steeper leeward side.

All these dunes, formed by wind blowing from one direction are moving types. Dunes formed by winds blowing at different times from all directions may be of any shape and are stationary. Stationary dunes may become covered with vegetation or have their outer surface cemented by lime. Such dunes have become stabilized. If wind erodes through a break in such covering, crater-like depressions called blowouts may form.

Loess deposits differ from sand dunes in that they are blankets of very fine material, often building to great thicknesses. The sand of the dunes is driven along the ground, but dust of the loess deposits is blown high into the air and may travel for hundreds of miles. Loess deposits are very widespread and are important economically as they form rich farmlands. Loess, like dunes, has its origin in wide river beds, in interior deserts, especially in glaciated areas where large amounts of finely ground rock flour are available from flood plains and outwash plains.

Loess is found on all of the continents. Asia's is derived from the Gobi Desert, from river beds, and from the glaciated areas to the north. Europe's loess deposits are derived from glacial outwash, as are many of North America's which also come from the semi-arid great plains and from river systems. The South American loess is derived from the western arid regions; Africa's comes from the northern deserts.

Loess is composed of unstratified, silt-sized angular particles. It normally erodes into vertical forms even steeper than badlands, with sink holes, cliffs and canyon-like streams. Vegetation which grew during deposition of loess and subsequently rotted, leaves vertical tubular openings in it, causing it to be more permeable in a vertical than a horizontal direction.

Alaska has a greater history of wind erosion and deposition than is generally realized, deposits of both dunes and loess being common. Dunes, mostly stabilized, are widespread on the Arctic Coastal plain, along the Kantishna, upper Kuskokwim, and Tanana Rivers. Loess deposits of Alaska occur along the Yukon, the Tanana, the Susitna, the Matanuska, and many other streams, as well as on Seward Peninsula and at Bristol Bay. Most of the Alaskan loess was derived from glacial streams.

The Arid Cycle In Fold Or Block Mountains

In the initial stage a mountain range is uplifted. Erosion immediately begins to develop consequent streams (gullies) down its flanks. Where gullies emerge into basins between the mountains, torrents which occasionally roar down build up fans of alluvial material; during the time between storms, the gullies are dry valleys. The finer material from the new mountains is carried to central parts of the basins, where playa lakes are formed after each rain. These lakes quickly evaporate, leaving level flats, called playas, which slowly build up to occupy increasingly larger portions of the basin.

The large, well-developed fans that are built where washes emerge from the hills gradually coalesce, forming a sloping surface called a bahada. As erosion continues, the mountain face retreats, leaving a sloping ramp-like bedrock surface between the bahada and the mountain. This surface, which is covered with a veneer of gravel, and which merges with the bahada, is called a pediment. Although opinion differs as to the mode of formation of a pediment, probably lateral cutting by the streams, erosion by sheetwash, and parallel retreat of the mountain face by weathering are the three most important factors in its development. The sloping surface composed of the bahada and the pediment is called a piedmont slope. During youth, the bahada comprises the major portion of the piedmont slope; as maturity approaches, the rock cut pediment forms a larger proportion.

Maturity is reached when a valley has been cut back from a basin far enough to capture the drainage of a higher basin. When this happens, the upper basin's playa is cut by gullies, and badlands form upon them.

In old age, the mountains have been reduced to such an extent that the climate, always dry, becomes even drier. Basins of higher elevation are stripped of their playas, laying bare the pediments, while winds slowly lower the playas, which in turn lower the local base level. Eventually, only isolated inselbergs are left, and the surface of the region is either bare bedrock or thinly covered with alluvium. This surface, corresponding to a peneplain in humid regions, is called a pediplain. Wind, operating more effectively in the dryer climate, gradually lowers the playas until the water table is reached, which is the base level of the region.

PROCESSES AND SURFACE FORMS OF COASTAL AREAS: MARINE CYCLE OF EROSION

The tremendous power of waves of the sea and lakes pounding on shores of the world is a very effective erosional agent. In Alaska, the work of the sea is of less importance than that of the streams and glaciers.

The coastline is the general area in which the sea abuts the land; the shoreline is the exact line where the water meets the land.

Classification of Coasts

Two systems have been devised to classify coasts and shores, neither of which is perfectly satisfactory. One is based on relation to structure and the other on relative vertical movement.

A Pacific type coast runs parallel to young fold mountain ranges, as do coasts of the Pacific Ocean. An Atlantic type coast cuts across structural trends and mountain folding. A submergent coast is one which has sunk with respect to water level. An emergent coast has raised relative to the water level. Submergent coasts are in general irregular, showing many bays and deep indentations where mouths of rivers have been flooded (drowned valleys). This type of coast (Europe and New England are examples), is called an indented or embayed coast. An emergent coast tends to be flat, with a straight shoreline. The submergent coast brings the shore into contact with hills, valleys, lakes, and mountains, while an emergent coast brings the shore into contact with land that has been recently under water, usually flat and gently sloping. Such a raised land, previously under water is a coastal plain.

When judging whether a coast is of the emergent or submergent type, one must weigh all evidence. The perfect Pacific type coast, for example, in which the bottom rises steeply towards the shore and continues up to the mountains after the shore is crossed will exhibit no differences in topography whether the land is raised or lowered.

Mechanics of Wave Action

An understanding of the mechanics of wave action and associated forces and currents is necessary to correctly interpret coastal forms. The wind, by its friction with water, agitates the water into waves. Where energy is being applied (wind is blowing), forced waves are found; if large, they are storm waves. Waves away from the source of energy are free waves or ground swells. The wave in the open sea, whether forced or free, unaffected by obstructions, is an oscillatory wave, each particle of water in it moving in a circular orbit. Theoretically, the water in a wave does not move forward, but practically, in forced waves, water moves forward, so that a particle in completing its circular orbit does not return to the same place, but to some point down wind. This process is called drift. The vertical distance from trough to crest is the wave height; the distance from crest to crest is the wave length. The farther below the surface, the smaller the orbit described by individual water particles. The depth at which no movement takes place is called the wave base, and is equal to the wave length. Because maximum wave length is about six hundred feet, the maximum depth of agitation is thought to be about six hundred feet; this is the greatest depth at which wave motion may affect sediments. The sea, as an erosional agent, is effective from a distance offshore where water has a depth of six hundred feet to a distance inland reached by its spray. This distance embraces the continental shelves.

The drift of surface water tends to make the waves lean forward, with steep fronts and sloping backs. When they are steepened so the crests fall forward or blow off, white caps are formed.

If waves, either forced or free, approach a steeply sloping shore or a cliff, the forward motion is eliminated, and the water moves up and down. If they approach a gently sloping shore, however, as soon as the wave base touches the bottom, horizontal movement is accentuated at the expense of the vertical, and wave particle motion becomes a forward leaning ellipse. When the wave reaches water having a depth equal to the wave height, the volume of water available in front is insufficient for the development of a full wave still being built up from behind. There is not enough water in front to support the crest, and the wave plunges forward and drops as a breaker, or surf. Water between breakers and the shore is moved forward by small waves, the swash, and moves back as undertow. Forced waves, approaching shore at some angle other than head on, strike the shore with an oblique or diagonal approach. Free waves tend to strike the shore everywhere head on in a parallel approach, because waves first reaching shallow water slow up, allowing the other waves to swing into position for a parallel approach. This tendency toward parallel approach concentrates the energy of waves on the points and headlands, and thus tends to erode them faster than the bays. Oblique approach to a shore creates, in addition to undertow which moves straight back, longshore or littoral currents, which flow along the shore.

Features of Coasts of Submergence

When a coast is first submerged, waves break against a land surface which ordinarily is neither vertical nor flat. If they should break against a cliff that rises from deep water, they will be hurled back with little damage to the cliff. However, whether they break against a cliff or a sloping shore, eventually they will dislodge boulders along joint planes, and erode inland, cutting a flat or gently sloping surface in bedrock. The result is a wave cut terrace or wave cut bench. At the same time, a wave built terrace is constructed of the eroded material. At the shoreward side of the terrace, a sea cliff develops, which may have a slight undercutting at the waterline, known as a wave cut notch. Where the notch is cut into easily eroded or soluble rock, a sea cave is formed. A headland or point may be attacked by waves from both sides, and eventually cut right through at water level to form a sea arch. If the arch caves in, leaving an isolated outlier, a stack is formed.

After enough fragments have been broken from the steep shores of a submerged coast to provide abrading tools for the waves, erosion proceeds rapidly. The wave cut platform is cut inland, and the detritus goes into the wave built terrace. As the terrace and platform become wider, the energy of the waves becomes dissipated in moving over them, and in grinding rock debris and moving the fine material seaward. Consequently, erosion of the sea cliff at the shoreward side of the wave cut platform becomes slower. The outline of the sea cliff, the wave cut platform, and the wave built terrace make up the shore profile. (See Fig. 6-18).

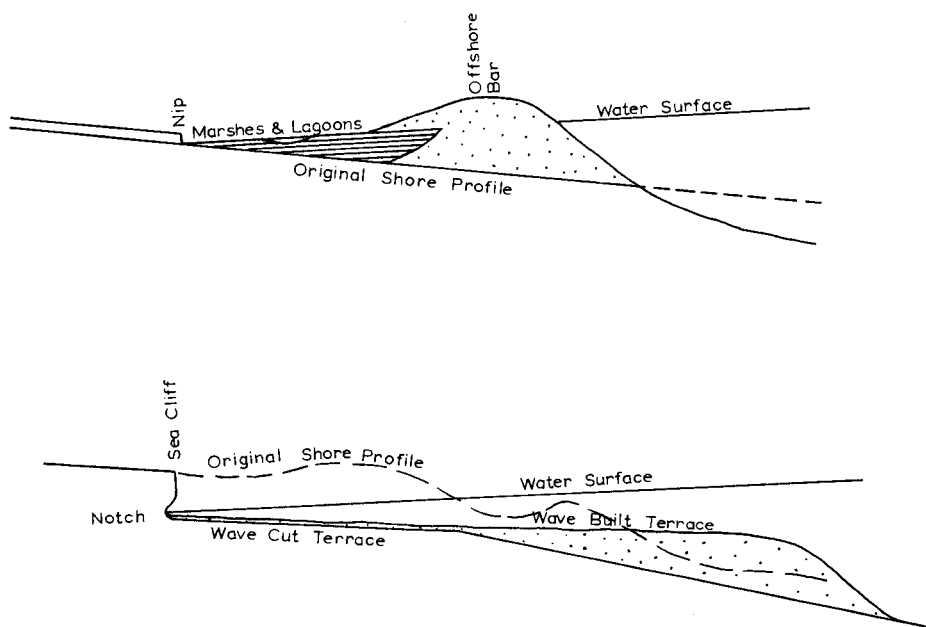


Fig. 6-18 - Shore Profiles -Top, Emergent Shoreline, Bottom, Submerged Shoreline

Erosion finally slows so that downward cutting of the wave cut platform practically ceases. Just sufficient rock material is supplied for the wave energy to be completely expended in grinding the material and transporting it seaward. A graded profile or profile of equilibrium (of the shore profile) has been established. This condition is analogous to the graded profile of a stream.

In a still later stage of marine erosion, little sediment is supplied from shore. Then, most erosion is effected by particles being moved back and forth by agitation of water at the bases of storm waves in areas beyond the wave built terrace. Eventually abrasion destroys the wave built terrace, so that a sloping bedrock surface extends unbroken from the wave cut terrace to the abrasion platform, cut by agitated sediment offshore. Products of marine abrasion, ground very finely by this time, ultimately come to rest at the outer edge of the continental shelf, which everywhere is 600 feet or less in depth. This edge may be extended outward for an indefinite distance through deposition of fine sediment, a very slow process, because the outer edge of the shelf drops off to the ocean depths.

If, as the sea makes its wave cut platform and wave built terrace, the land gradually sinks with respect to sea level, erosion can proceed at maximum rate, for a wide expanse of platform need not be crossed by waves to reach the shore. Consequently, they strike the shore with undiminished force. Under such conditions very wide plains of marine erosion are formed, a few of which have been uplifted and preserved. In many parts of the world, of course, ordinary raised wave cut platforms are to be seen.

Features of Coasts of Emergence

It has been noted that the coastline of emergence tends to be gently sloping, because it formerly was a region of deposition. If faulting or folding elevates a coast so that deep water extends in to the shoreline, however, the shore may resemble somewhat that of a submergent coast. If faulting produces the uplift, there will be an initially straight shore, emergent along the scarp. However, this shore soon becomes irregular due to differential erosion of the various rocks exposed. These irregularities do not develop to large size, because as soon as a point or headland develops, it is attacked with increased force; such a shoreline with small irregularities is referred to as crenulate.

In a shallow slowly emergent coast, that part of the old bottom which rises above the sea becomes a coastal plain. Waves break on the shallow floor before reaching shore, and do most of their eroding offshore. Material from the zone of erosion is carried to the shore; if gravel, to form a beach ridge; if sand, to form a beach. The shore line by such deposition gradually moves seaward, developing a foreland, or strand plain. Such a coast being built seaward, is one of progradation.

Small waves break on shore to produce a temporary small cliff, called a nip, in unconsolidated material of the beach. The big waves break some distance offshore, taking material from the bottom and piling it into the equivalent of a beach or beach ridge. This material eventually may be built up by storm waves to water level or above; it is then an offshore bar or barrier beach. Water between the offshore bar and the shore is called a lagoon. The offshore bar gradually advances until it merges with the shore line and moves inland as a dune. The shoreline itself then is a low cliff; the shore has reached its profile of equilibrium. Fig. 6-18 shows an emergent shoreline before reaching equilibrium.

The Cycle of Marine Erosion

As the emergent coast ordinarily is a place which has already undergone part of a cycle of marine erosion, emergence usually does not start a new cycle, unless it is by faulting or steep folding as already explained. The initial step in the cycle, therefore, is normally submergence, which brings deep water near the shore.

In early youth, the submerged coast reflects the previous land topography. Mouths of rivers become bays called drowned river valleys, or rias. In early youth they are numerous, and the coast is a ria coast. Where the major structure runs parallel to the coast, as in the Pacific type, drowned valleys tend to form harbors parallel to the coast connected with the sea by narrow mouths. San Francisco harbor is typical. These features, derived from the old land topography, are supplemented in youth by such forms as stacks, sea arches, caverns, sea cliffs, notches and wave cut platforms. Erosion soon slows, and detritus begins to accumulate and to straighten the shore line. Early youth is over and late youth and maturity are beginning.

The rock products are soon worn down to finer particles, which are either moved straight out into deep water or moved laterally along shore by longshore currents. Where wave action is concentrated on headlands, with consequent strong erosion, longshore currents effectively transport rock fragments away, into the bays. Usually, larger material is dropped near the points, and only fine sand reaches the heads of bays, to form bayhead or pocket beaches. The bays slowly fill up as headlands are eroded, straightening the shoreline.

The smaller irregularities of the coast are closed in this way, but wider deeper bays present too large an opening to be completely filled with detritus by longshore currents. Sometimes the waste is deposited as bars on either side forming a winged headland. More often after minor bays have been filled in, strong longshore currents develop along the unbroken stretches where much detritus is available from the beaches. Where these currents encounter deep water at the mouth of a bay, they slow down and drop their loads, gradually building an underwater bar across

the bay. Storm waves later build the bar above water to form a bay mouth bar, in the same way an offshore bar is built. Once the bay mouth bar is built, longshore currents can proceed beyond the bay, carrying their loads of sediment further. If tides are large or if much fresh water is entering the bay, a small opening is left in the bar, large enough to handle the flow of water in and out, yet small enough not to interfere with the drift of sediment by longshore currents. If the flow of water is small, it may be handled by seepage through the bar, and no opening need exist. A bay mouth bar in the process of being built, that is, one which extends out from a headland and stops without going completely across, is called a spit. If a point is so situated and shaped that it directs longshore currents out to deep water, the spit grows seaward. This feature is called a cusped foreland. If waves or cross currents push the cusped foreland back or sideways, a recurved spit or hook is formed.

A spit growing from an island toward the shore may eventually link the two, forming a tombolo, which in tying the island to the land, forms a tied island.

After the bay mouth bars and offshore bars have been built, filling of the larger bays begins. Lagoons behind the bars begin to fill with sediments from land, vegetation gets a foothold, and eventually the lagoons become marshes. The coast becomes straighter and simpler, and is now mature. Steep shores mark the places of former headlands; flat portions mark former bays. When the whole shoreline has been eroded farther inland than the former extent of the deepest bays, full maturity has been reached. The shoreline of the entire coast is composed of low cliffs, and is similar to that of an emergent coast after offshore bars have been pushed back to join the land.

Old age in the cycle of marine erosion is reached when the land also is in old age; then the sea meets a gently sloping low land in a straight line. Crustal movement has been so active, however, that it is doubtful if any coasts of old age exist today, although they must have existed during quiet periods of geologic time, when shallow seas covered much of the continent.

The fluvial cycle is initiated by uplift; the marine cycle by depression of the land. As in the fluvial cycle streams may be superposed upon differing structures, so coasts may cut across different structures. Such a coast is called a contraposed coast.

Elevated Shorelines

In many places, elevated shorelines are evidence of recent crustal changes. Perhaps the most striking examples of such changes, because they are very recent, are connected with Pleistocene glaciation; these have already been discussed. Such raised beaches escape rapid destruction by fluvial erosion because they are usually permeable. Raised sea cliffs, on the other hand, are attacked and soon worn down. Another factor connected with glaciation which has had an influence on the coast is the amount of water tied up as ice during glacial ages. It has been estimated that at the height of glaciation, sea level was lowered about three hundred feet, and that if all the ice in the present glaciers were melted, it would be raised about one hundred feet.

PROCESSES AND SURFACE FORMS IN UNDERGROUND SOLUTION AREAS

Ground Water

Underground water, or ground water, is present almost everywhere. Usually there is a depth called the water table, below which the ground is saturated. Water above this level percolates down until it reaches the water table. Ground water resting on an impervious layer higher than the regular water table in the region is called a perched water table. Lakes are areas where the water table reaches the surface; and swamps are areas where it comes very close to the surface. Ordinarily, to obtain groundwater, a well is driven or dug to below the water table and water pumped out. In order to sink a shaft below the water table in thawed ground (wet ground to the miner), it is necessary to crib the hole tightly and pump continuously.

Sometimes ground water enters a permeable layer between two impervious layers. If these layers slope down off a hill or mountain, water in the lower parts is under hydrostatic pressure from the water higher up. If the permeable layer is tapped by a well, pressure may be great enough to cause water to flow to the surface and shoot into the air. This is artesian water.

Karst Topography

Ordinarily, water in the ground acts in conjunction with running water to produce the familiar landscapes associated with the fluvial cycle. On certain types of soluble bedrock, principally limestone, however, ground water dissolves enough underlying material to produce distinctive features on the surface. These features, taken together, make up karst topography, and the processes act in the karst cycle. (The word karst is derived from Carso, a name applied to an area mainly in Yugoslavia, along the Adriatic, which is the type locality for karst topography). In discussing permafrost in an earlier part of this chapter, mention was made of thermokarst features, caused by the underlying support being melted away. The results of

ground ice melting and of limestone dissolving are analogous; the overlying material subsides.

When this action occurs by solution, the phenomenon is known as *solution subsidence*. The depressions formed by this subsidence are known as *sinks* or *sink holes*; they may be dry, or they may contain lakes. Uneven subsidence over a large area may produce a hummocky, lake-dotted surface. This process is the third which may produce hummocky topography, the other two being landsliding and glaciation. Conical hills left after subsidence of a region undergoing karst solution are called *hums*. All these features may form in either coral or limestone.

Lapies or *karren* is a surface developed on rock, principally limestone, by heavy rains. It consists of deep furrows separated by narrow ridges, due to differential solution along fissures and other weaknesses. In regions of heavy rainfall, sandstone or basalt may develop this surface, showing that when ample precipitation is available, features due to solution can be superimposed over features due to fluvial processes.

The sink hole is a variation of a more fundamental feature, the *doline*, which is any vertical solution cavity. Dolines often are aligned along joints which are seepage ways. When dolines coalesce, they form *uvalas*, which may be aligned with joint fissures or along the courses of former surface valleys. Uvalas thus formed in elongated patterns are called *valley sinks*.

Caverns are underground openings in the rock caused by solution by water, enlarged perhaps by roof collapse after the water table has dropped below the cavern level. Dry caverns at different levels are believed to have been formed by water, but preserved by successive uplift of the region. The exact mechanism of cavern formation is imperfectly known. Many caverns are gradually filled with *dripstone* and *flowstone*, limestone deposited from dripping and flowing water.

Tunnels and one type of *natural bridge* are remaining sections of streams which once flowed underground, but which by caving or solution, gradually lost most of their cover.

In the fluvial cycle, uplift brings swift rejuvenation with accelerated erosion of the highlands and filling in of the lowlands. In the karst cycle, however, surface drainage ceases after late youth. Water falling on the surface disappears underground and can do little surface eroding. Certain large closed basins in karst regions are thought to be depressed fault blocks or *grabens*, which have been preserved because of this lack of fluvial erosive power. The basins, which contain up to one hundred square miles, are called *poljes*. During periods of great rainfall, their bottoms may be flooded through underground ducts. Floodwaters bring in sediment which is deposited on the floors, keeping them smooth.

The chalk of England and France behaves differently from other limestones and develops some special forms. Chalk absorbs and holds large quantities of water, a characteristic which inhibits solution. Trunk streams are able to maintain their courses as normal surface streams through chalk. Lowering of the water table resulting from downcutting of these streams causes some of the tributaries to lose their water by seepage, and leaves them as *dry valleys*, which may become *dry hanging valleys*.

The Karst Cycle Of Erosion

The karst cycle starts when surface water reaches the soluble material, either because the overlying insoluble material erodes away, or by way of fissures and joints. The first features developed are *dolines* and *karren*. During youth, the dolines gain in size and number. Youth has ended when all runoff has been diverted to underground streams or other solution passages.

When the surface of the area has been converted to *uvalas* and *hums*, many of the uvalas become *blind valleys*, which have steep sides and ends. Water flowing in such a blind valley, upon reaching the lower end, flows underground.

In old age, the surface reaches either the water table or an insoluble layer; and surface stream drainage again is established. The ridges between uvalas are lowered, and near *planation* results, with isolated *hums* scattered through the country.

GEOMORPHIC FEATURES DUE TO CONSTRUCTIONAL FORCES

Several times this chapter has emphasized the concept of constructional forces and destructional forces working against each other to shape the land. The different destructional agencies and some forms they create on different pre-existing landscapes have been described. These destructional agencies are: running water in humid, temperate, and arid regions; wind, moving ice, waves and currents, and ground water.

Forms developed by water eroding in fold mountains were described under the fluvial processes, and the effect of rock structure on drainage patterns was explained, e.g., radial drainage from a dome.

Some constructional features of the earth, however, are directly responsible for certain forms whose origin cannot be completely described without describing the structural feature. Among these visible direct manifestations of the original constructional processes are volcanoes, coral

growths, and fault blocks. Again, it must be emphasized that any type of erosional process may operate on any type of constructional feature.

Topography Of Fault Structures

The mechanics of faulting and the appropriate descriptive terms are discussed in Chapter 4. Fault movement may be vertical, horizontal, oblique or rotary, but vertical movements find the greatest surface expression. The commonest type of fault feature is the fault block mountain. In this form, tension causes a normal vertical fault to develop, and the upper block, the one ending in the fault scarp, is tilted back. The fault block mountain has, then, in cross section, a steep front, the fault scarp; and a gentler back, the tilted back slope.

The mountains of Alaska - the Coastal Ranges and the Brooks Range - are complex mountains, the products of both folding and faulting; as yet no fault blocks have been recognized in them. In many places in the western United States, however, fault block mountains comprise major portions of the landscape. The Sierra Nevadas consist of a fault block, probably the largest in the world. The scarp faces toward the east, and the back slope grades down westward to the Great Valley. The entire Basin and Range area of the west is composed of fault block mountains and inter-mountain basins.

Fault scarps may be recognized by several characteristics. If very new, scratches or slickensides may still be visible. New uplift on an old fault scarp may disturb the talus that had accumulated at the base of the scarp before the new movement; such a disturbance is evidence of recent uplift. Whether new or old, the fault scarp tends to make a straight or gently curved line at the surface. Scarps due to weathering, on the other hand, tend to develop irregular lines to follow differences in resistance of the rocks. Direct geological evidence of faulting is provided if a particular bed, series of beds, dike, or other features can be found displaced on opposite sides of a scarp.

Another way in which fault scarps may be recognized, after erosion has destroyed slickensides and other direct evidence of faulting, is by triangular-shaped faces along the scarp. Streams crossing the scarp cut triangular shaped cross sections, point down. Therefore, portions of scarps remaining between adjacent streams, are triangular shaped, point up.

Where movement has been intermittent, wineglass valleys, emerging from the scarp, may develop. A wineglass valley has a wide cross section in its upper part, and a narrow canyon where it comes through the scarp. This condition is due to the upper parts of the stream attaining maturity since the initial uplift, while the lower canyon section is continually presented with more rock through which to cut, keeping it in a perpetual state of youth.

Fault block mountains, with their steep scarp faces and gentler back slopes, are perhaps the largest and most frequently encountered fault-created geomorphic features. However, others, some of them hundreds of miles in extent, deserve mention. Horsts and grabens were defined in Chapter 4. The horst is an upraised block, bounded on all sides by faults, and the graben is its downthrown counterpart. Horst mountain masses are known in many regions of fault mountains. They may be relatively flat topped and have steep sides.

The valley resulting from graben faulting are called rift valleys, and are sometimes of great length. The great African rift extends from Palestine, four thousand miles south into Africa. Death Valley in the United States is considered a rift valley. Rifts have relatively steep sides and flat floors, and parts of them may be below sea level.

A different type of faulting is large scale horizontal thrusting. When horizontal stress is applied to some portion of the Earth's crust, the rocks first bend; but under further stress, they fault along a relatively horizontal plane. If the stress still continues, the upper mass is pushed forward for a considerable distance, sometimes several miles, as an overthrust. A mountain may thus be formed, cut off from the underlying rocks at its base by a horizontal fault. This feature is sometimes called a mountain without roots, sometimes an outlier.

Although many mountains of the world have been formed by overthrusting, to prove their origin by geomorphic evidence alone is usually difficult; structural evidence must also be found.

Overlapping thrusts are called *dekken* or *nappes*. Sometimes an overthrust segment is attacked by erosion and left as an outlier completely separated from rocks of its own formation. This outlier is called a *slippe*, and is peculiar in that an older rock may overlie younger rocks. A parallel feature is a *window* (German, *fenster*), an area of younger rocks exposed by erosion within the area of an overthrust. The name is suggested by the fact that it is a "window" through which the younger rocks below are seen.

Volcanic Forms

Volcanic activity produces distinctive forms such as cones, craters, and plateaus. Volcanoes are numerous in the volcanic areas of Alaska, these forms comprising a large portion of the landscape.

The difference between intrusion of magma and extrusion of lava is discussed in Chapter 3. Extrusion of lava is the mechanism producing the land forms of volcanic regions. Although the

term lava is applied to all material ejected during vulcanism, it is usually taken to mean only the liquid or pasty molten rock material which flows from the volcanic opening. The fragmental materials blown into the air, referred to as pyroclastics, or volcanic ash, are called, in order of decreasing size: volcanic bombs, lapilli, volcanic ash, and volcanic dust. (See Chapter 3). Rocks formed by consolidation of the coarser material are called volcanic breccia, and of the smaller, volcanic tuff.

Magma varies in composition from acidic or siliceous, to basic. Because acidic melts are relatively viscous and basic melts are relatively fluid, the two behave differently when in movement or when being extruded. This difference in behavior is reflected in the landforms which result.

The largest forms resulting from vulcanism are lava plateaus, some of which attain a great enough size to comprise second order geomorphological features. They result from the building up of successive layers of basic fluid lava (basalt) which wells out from large fissures. They cover hundreds of thousands of square miles, and where undivided, are nearly horizontal planes. The lava, where it encounters topography of high relief, flows around high points and fills in low places. Isolated peaks of underlying rock, projecting above the lava as "islands," are called steptoes.

Where the ejection of material from a fissure occurs with explosive force, a volcanic rift is left. Most of the ejected material then is pyroclastic.

Ranging in size between the tremendous fissure extrusions which produce large lava plateaus and the explosions which eject only as much material as is removed from the rift, are the ordinary volcanic eruptions, either of lava or of pyroclastic material, which produce enough material to fill valleys, dam streams, and otherwise modify existing drainage.

Because lava usually is both hard and permeable, it is often more resistant to erosion than the rocks over which it has flowed. For this reason, lava cappings are often found at higher elevation than the rocks with which they are associated; and since lava originally filled the low places, or valleys, inversion of relief occurs. Former low areas, when filled with lava, tend to become high areas. When lava beds alternate with easily crumbled volcanic ash beds, the high regions, capped with lava, often stand with vertical, scarp-like walls.

The volcanic feature traditionally associated with vulcanism is the volcanic cone, or one with a very broad base in relation to its height. (The Hawaiian Islands are examples of this type.) A shield cone is built up of innumerable flows, each of which is long, narrow, and thin. This fluid type of lava solidifies intoropy lava, called, in Hawaiian, pahoehoe (pa-hoy-hoy), or into blocky lava, called aa (ah'-ah'). Pahoehoe exhibits a ropelike surface; the surface of aa is broken into slabby blocks. Composition and gas content presumably determine which type of lava develops.

When siliceous, viscous lava flows from a circular vent, the resulting cone is steeper than the shield cone, because this type of lava stands at a steeper angle and solidified quicker. This type of cone is called a dome cone.

Material, ejected with explosive force as pyroclastics or cinders, may fall back around the vent, building a cinder cone. Such cones are steep, but are seldom higher than one thousand feet.

When lava flows and cinder eruptions alternate, a composite cone is built up. The cinders provide the steep slope and lava provides the cementing bond. The classic volcanic cones of the world are of this type.

The openings or vents at the top of the cones vary greatly in size. Composite cones have vents narrow and deep; cinder cones have wider steep-sided vents. These are relatively small openings and are called craters. Some shield cones have large vents, perhaps miles across; these large vents are calderas. Between eruptions they may be floored with flat "lakes" of frozen lava, and have steep walls. Many ancient calderas are known, some of which are larger than the active Hawaiian ones. Crater Lake, Oregon, is six miles in diameter, and Aniakchak on the Alaska Peninsula is over thirteen miles across. Calderas are formed by collapse or explosion, or by both. Tremendous explosions of a magnitude capable of causing calderas have been known in historical time, such as the one at Krakatoa in 1883.

When a new cone and crater rise within a caldera or crater of an earlier cone, the feature is known as a cone in cone, or a nested crater. A parasitic or adventive cone is one formed on the side of a larger cone. A volcanic spine is a long narrow plug or spine of rock which is forced up by viscous lava under pressure from below; spines usually form from acidic lava. Where lava breaks out of the inside of a cone, a breached cone results.

Geysers, hot springs, and fumaroles are minor manifestations of vulcanism. The fumarole is an opening in the earth from which steam and a small amount of gas issues. Most of the steam is formed from ground water which has encountered hot rocks or hot gases at depth. Hot springs are fumaroles which receive more water than they can convert into steam. Geysers are openings into which surface water has flowed. At intervals steam pressure builds up sufficiently to eject the water, after which the water flows back to await the accumulation of enough steam pressure to repeat the process. Often deposits of silica or limestone are built up around hot springs or geysers.

Volcanic flows and cones weather and erode to produce some unusual features. It has been mentioned that flows often produce mesas or flat topped, straight sided eminences. The streams flowing from a volcanic cone develop radial drainage; composite cones, consisting of cinders with circular dikes of lava, may develop annular drainage as a result of the streams being forced to flow around the cone by the dikes. Lava, on cooling, may develop hexagonal jointing, giving rise to long blocks with hexagonal sections. Sometimes these weather to form cliffs on the edges of flows. Such cliffs are called palisades.

Coral Structures

Another constructional geomorphic form is the coral reef. Coral forms are different from any others and can be explained only in terms of coral growth. In Alaska they are unimportant, so here only the major types are defined.

The fringing reef grows along shores of islands and continents, forming a wide shallow platform of coral fringing the shore.

Coral banks are wide shallow banks covered by a coral crust.

A barrier reef is a narrow strip of coral above water, sometimes encircling an island or group of islands; and sometimes paralleling a coastline. The water between the reef and the shore is shallow, and called a lagoon.

Closely allied to the barrier reef is the coral atoll, a roughly circular ring-like island, with one or more openings through which the tide flows in and out. Inside the ring is a shallow lagoon. If subsidence should progress faster than corals can maintain their growth, a drowned atoll, or one below sea level, results.

PHYSIOGRAPHIC PROVINCES

At the beginning of this chapter it was stated that geomorphic features were divided into those of first order, second order, and third order. First order relief features are the continents and ocean basins; second order relief features are mountain systems, plateaus, and features of like size; and third order relief features are individual mountains, streams, and other such smaller entities.

The second order relief feature may be considered as an area made up of one type of structure that has been acted upon by one or more processes which produced a distinctive landscape. This area is called a physiographic province. In going from mountains to a plateau and from the plateau to a coastal plain, a traveler traverses one physiographic province after another. Physiographic provinces have definite climates and are referred to by geographic names, e.g., the Brooks Range or the Arctic Slope. The geographic name does not indicate, however, what type of second order relief feature is referred to, so classifications of geomorphic units have been devised. One of the most complete systems of classifications, that appearing in "Geomorphology" by O. D. von Engel, Macmillan and Co. appears below, by permission of the publishers.

In this system, a division into two major parts, simple structures and disordered structures, is made first. Simple structures are more or less flat, evenly sloping, or gently curved, whereas disordered structures are warped or faulted.

The simple structures are divided into three groups: "A" includes those composed of unconsolidated or poorly consolidated material of simple layered structure. "B" includes those of consolidated rock having simple uniform structure. "C" units are composed of calcareous rock.

In the class of disordered structures there are two groups. Group "D" includes those folded or faulted structures composed of or including sedimentary rocks. This group includes most of the mountains of the world. Group "E" is composed of the ancient rigid shields, which have maintained themselves above sea level for much of geologic time. The topography of this class varies, the distinguishing feature is the lack of sedimentary rocks. The Canadian shield is such a unit, represented by a plateau.

Within each group are several smaller subdivisions, each having a name descriptive of the feature.

Classification of Geomorphic Units, based on O. D. von Engel

Class I - Simple structures

Group A - Units of simple structure and unconsolidated sediments.

1. Coastal plains. The flat sloping area between the sea and the hills, formed by emergence of the land.
2. Piedmont plain. The sloping plain formed by outwash from hills or mountains.
3. Tundra plains. This unit, which is represented in Alaska by the Arctic Slope and parts of Seward Peninsula, is not separated from the rest because of its origin, but because, being mostly frozen, it behaves somewhat like solid rock. Tundra

plains may originate in a number of ways; the Alaskan Arctic Slope originated by emergence from the sea as a coastal plain. For a better understanding of this unit, the reader should refer to the discussion of permafrost.

4. Flood plains, delta plains, and lake bottom plains. These are formed by deposition of sediments by water in a valley or lake basin. A fine example of a flood plain is the flats of the Yukon.

5. Desert Areas. The sandy area in an arid region which is the counterpart of the flood plain, delta plain, or lake bottom plain in a humid area. It frequently exhibits sand dune topography.

6. Glacial plains. The undulating surface of drift spread over a preglacial surface of relatively low relief. The plains of the northern midwest United States are typical.

7. Loess plains. Regions of windblown material.

Group B. Units of simple structure and consisting of consolidated sedimentary or igneous rock.

8. Interior plateaus. Flat dipping regions underlain by sedimentary rocks, as the Great Plains.

9. Nested saucer basins. Sedimentary or stratified igneous rocks which have taken on a bowl shaped structure, probably from sag. The Paris Basin is a good example.

10. Lava flow plains and plateaus. Flat, thick, built-up lava flows. The Columbia Plateau of Washington, Oregon and Idaho is typical.

11. Volcanic cones. Cones composed of volcanic fragments, lava, or both.

Group C. Simple structures of consolidated calcareous rock.

12. Karst Areas. Regions of massive limestone cover on which solution processes are active.

13. Coral Islands. Any coral reef raised above sea level.

Class II - Disordered Structures

Group D. Folded and faulted structures involving sedimentary rocks.

14. Dome uplift. Flat lying strata forced into a dome by igneous material moving in from below.

15. Fold mountains. Flat lying beds which have become corrugated by horizontal thrust. Thrust mountains of low angle fault origin are included.

16. Fault block mountains. A block of the crust that is moved up or down along faults, usually with rotation.

Group E - Ancient rigid masses or shields.

17. Ancient igneous and metamorphic shields which have maintained their position above sea level for long periods of geologic time.

18. Peneplaned sedimentary and metamorphic rock regions. Units composed of layered rocks on edge, or dipping steeply, which have been planed off or truncated.

19. Continental glaciers. Huge domes of solid ice. Although uniform in composition, they are frequently deformed, and move.

The physiographic provinces of Alaska are listed below and classified according to the foregoing system.

Southeastern Alaska and the Alaska Range and adjacent mountains comprise a physiographic province classed as group D, folded and faulted structures involving sedimentary rocks. Units of 14, 15, and 16, dome uplifts, folded, and fault block mountains are included. As one progresses to the west, volcanic cones, 8-11 becomes increasingly frequent.

The Brooks Range is composed of units D-14, 15, 16, mountains of dome, folding, and faulting origin.

The Arctic Slope, as stated before, is both A-1 and A-3, a coastal plain which has become a tundra plain because of the cold climate.

The interior hills are partly D-14 and D-15, domes and fold mountains, with some faulting, D-16.

The wide, river flat lowlands of the interior are A-4, floodplains, some of which fill structurally downwarped basins.

References

General

- Cotton, C. A., 1942, *Climatic Accidents*: John Wiley and Sons, Inc., New York
 Emmons, Thiel, Stauffer, Allison, 1955, *Geology*: McGraw-Hill Book Co., Inc., New York
 Lobeck, A. K., 1939, *Geomorphology*: McGraw-Hill Book Co., Inc., New York
 Thornbury, W. D., 1954, *Principles of Geomorphology*: John Wiley and Sons, Inc., New York
 von Engel, O. D., 1942, *Geomorphology*: The MacMillan Co., New York
 Cold Land Processes:
 Bryan, Kirk, 1946, *Cryopedology, the study of Frozen Ground and intensive frost action with suggestions on nomenclature*: Am. Jour. Sci. v. 244, p. 622-642

- Eakin, Henry M., 1916, The Yukon-Koyukuk Region, Alaska: U. S. Geological Survey Bull. 631
- Leffingwell, E. deK., 1916, The Canning River Region: U. S. Geological Survey Prof. Paper 109
- Muller, S. W., 1947, Permafrost: J. W. Edwards, Inc., Ann Arbor, Michigan
- Péwé, Troy L., 1952, Geomorphology of the Fairbanks Area, Alaska: Doctoral thesis, Stanford University
- 1955, Origin of the upland silt near Fairbanks, Alaska: Geol. Soc. America Bull. v. 66, p. 699-724
- Taber, Stephen, 1929, Frost Heaving: Jour. Geology, 3, 37, p. 428-461
- Washburne, A. L., 1956, Classification of patterned ground and review of suggested origins: Geol. Soc. America Bull. v. 61, p. 823-865
- Glacial Processes:
- Hopkins, D. M., 1955, Quaternary History of Seward Peninsula, Alaska: Unpublished Doctoral thesis, Harvard University
- Matthes, Francois E., 1942, Hydrology, Chapter V., Glaciers: McGraw-Hill Book Co., Inc., p. 149-215, New York
- Mertie, J. G., 1925, Geology and gold placers of the Chandalar district, Alaska: U. S. Geological Survey Bull. 773, p. 215-263

Chapter 7

MINERAL DEPOSITS

INTRODUCTION

Before beginning the study of mineral deposits, it is necessary to define a few fundamental terms. A mineral was defined in Chapter 2 as a naturally occurring substance of definite composition, and, with few exceptions, a definite crystal shape. In studying ore deposits, the meaning is usually expanded to take in oil and coal, although coal is actually a rock. A mineral deposit is a concentration of useful minerals. An ore is a mineral-bearing substance (usually metallic) which can be mined at a profit, and an ore deposit is an economically mineable concentration of minerals. What constitutes an ore deposit may change with price and mining costs; therefore, in this book the more general term "mineral deposit" is used. Protore is material which contains some valuable minerals, but not in sufficient concentration to mine. Highgrade or higrade is rich ore; lowgrade is poor ore.

An ore mineral is one from which a useful metal can be extracted; there may be one or many in any particular deposit. If the ore contains only one ore mineral, it is a simple ore; if more than one, it is a complex ore. Gangue is worthless material accompanying ore minerals, and gangue minerals are minerals composing the gangue. Precious metals are gold, silver, platinum, or a metal of equal value; base metals are all others. Country rock is the predominating bedrock in an area. Wall rock is the rock immediately surrounding a deposit. It often happens that a deposit is worked for one mineral, say gold, and that other minerals, e.g. sphalerite, arsenopyrite, and galena are present, but in such small quantities as to be worthless. Such minerals are still considered ore minerals, even though in the particular ore deposit they are worthless. Any mineral deposit occurring in place in bedrock is called a lode to distinguish it from deposits formed by processes of erosion.

Mineral deposits are formed in many ways; and because their study is the branch of geology most directly related to mining, men for centuries have tried to classify them so that each deposit could be put into an appropriate pigeon hole. By so doing, it was hoped that once a deposit was classified, many general facts concerning it would be known. Thus classification would facilitate the search for, and exploitation of, a particular deposit; this is the primary purpose of classification, and all classifications have produced this desired result to some extent.

Because all mineral deposits originate in magmas (see Chapter 3), those formed by igneous action are called primary deposits. Those formed by subsequent erosion or solution and re-sulting deposition, are called secondary deposits. Primary deposits are further divided into those formed at the same time as the parent rock, syngenetic deposits, and those formed later, epigenetic deposits. An example of syngenetic deposits is a body of basic igneous rock in which are concentrated bands of chromite, as found on the Kenai Peninsula, Alaska. An example of an epigenetic deposit is an ordinary gold bearing quartz vein filling a fissure, as found in numerous Alaskan localities. In connection with these terms, it might be well to remember that "genesis" means origin, "syn" means "together with", and "epi", as used here, means "outside of".

The term hypogene is sometimes used for primary, and supergene for secondary. As the simpler words "primary" and "secondary" serve just as well, they will be used here. The confusion that exists as to whether these words are exactly synonymous will be discussed later.

BRIEF SUMMARY OF EVENTS IN THE FORMATION OF MINERAL DEPOSITS

As introductory to the classification of deposits, a general discussion in chronological order of the series of events commonly believed to occur during deposition of minerals is in order. It will be recognized that this sequence is practically the same as the sequence of rock formation (See Chapter 3). In Chapter 1 it was explained how the earth's crust is "floating" on the underlying semi-plastic interior, and how during diastrophism, the crust is weakened and crumpled; faulting occurs, and mountains are formed. This crumpling may cause a release of pressure on a portion of the earth's interior, and rock in that area may become liquid and be forced toward the zone of reduced pressure. Depending upon conditions which the magma meets in its movement toward zones of reduced pressure, it may melt its way along, or advance by breaking off blocks of country rock in its path, or squeeze itself into fissures or between bedding planes. It may come to rest deep within the earth or may issue at the surface in the form of lava flows.

Whether or not the magma moves after it becomes liquid, the first stage in the formation of mineral deposits, and incidentally, in the formation of different igneous rocks, is a separation of the magma, called magmatic concentration. Several processes have been proposed to account for this separation. In Chapter 3 it was shown that minerals crystallize from magma in definite sequence, starting with the heavier dark minerals and calcic plagioclase, then amphiboles and albite, biotite, orthoclase, muscovite, and quartz. Some of the earlier minerals, being heavier, may settle; consequently the more basic igneous rocks have a tendency to form in the lower parts of the magma chamber by gravitational settling. After partial crystallization further movement could conceivably squeeze liquid portions into segregations; this process is called filter pressing. If the crystals move with the liquid, friction with the sides of the cavities tends to separate crystals of one composition from liquid of another. A slow convection current within the magma might bring material to the cool borders of the chamber, where it could crystallize out.

All of the processes of magmatic concentration have not been mentioned, but those noted demonstrate that separation of magma in its chamber does occur. Now, if it is considered that the magma contains valuable metals which may form minerals that are segregated, the origin of syngenetic deposits becomes apparent. Deposits of this class occur mostly in basic rocks. Among these deposits are chromite, magnetite, diamonds, corundum, ilmenite, and platinum; although the latter, with few exceptions, must be concentrated into placers or occur as a by-product, before it forms a mineable deposit.

As crystallization of the rock progresses, the liquid remaining becomes more and more acidic, and rocks of composition tending toward granite are formed in different parts of the magma chamber. Toward the end of the cooling, many elements of commercial value as well as compounds of certain volatile substances such as water, boron, fluorine, chlorine, sulfur, phosphorus and others, become concentrated in the liquid. These volatile substances, called mineralizers, cause the remaining liquid to be more fluid. The magma at this point is in a transition stage between an igneous solution or melt, and an aqueous "watery" solution, and is said to be in the pegmatitic stage. Because of the liquid's composition, crystallization is slow, resulting in very large crystals; and pegmatites (as rocks formed from such liquids are called) usually are found in dikes extending out from the earlier formed rocks and sometimes cutting across the boundary of the intrusive. This indicates that the intrusive started to harden around the edges before expulsion of the pegmatitic material. The first pegmatites to form have about the same composition as granitic rocks, but later ones may contain minerals of tungsten, tin, beryllium, uranium, titanium, fluorine, and gem minerals. Sometimes pegmatite dikes form ore deposits, which belong to a late stage of magmatic concentration. Sulfide ores are seldom formed at this stage.

The next step in the formation of mineral deposits, one which begins before the final consolidation of the rock and continues afterward, is the expulsion of gases and liquids which have heretofore been in solution in the magma and which have absorbed many minerals concentrated in the last remaining magma. During this stage are formed all remaining types of primary deposits; these deposits, along with the last formed pegmatitic dikes, are the epigenetic deposits. Both gases and liquids are commonly believed to carry the minerals to their place of deposition; but whether the liquid came directly from the magma, or passed through a gaseous stage is still debated. Either way, they are known as "juvenile (young) waters," to distinguish them from "meteoric waters," which are surface waters percolating through the rocks of the earth's crust.

Naturally, large quantities of gas and liquid, buried under a considerable depth of overburden, are under great pressure and must move in any direction of decreased pressure. This movement follows natural routes of relatively open spaces, such as fault zones, porous rock, or, in shallower regions, fissures and cavities in the rocks. With decreased pressure and temperature, and by chemical reaction with rocks which they may encounter, the solutions, liquid or gaseous, begin to deposit their dissolved burden of minerals. When the transporting agent is water, resulting deposits are called hydrothermal (hot water) deposits. Except where pressures are low enough (toward the surface) to allow natural cavities to stay open, simple filling of openings cannot take place, and the liquid must first dissolve some of the country rock and then deposit a bit of its dissolved mineral in its place. This process is known as replacement or metasomatism. A special kind of replacement by material carried in vapors occurs when a large, deep seated body intrudes sedimentary rocks, especially limestones. The extremely hot emanations entering the surrounding rocks change the minerals, and consequently the rocks, by contact metasomatism; and when valuable minerals are formed in rocks near the intrusive, contact metasomatic deposits occur. (An older term contact metamorphic deposit is not in general use today, because metamorphism denotes change without the addition of new material). "Metasomatism," however, implies addition of new material, as well as heat and pressure.

Deposits formed around hot springs, fumaroles, and geysers have furnished much information on the relationship of igneous rocks to mineral deposits, because they contain minute amounts of many valuable metals; and thus furnish proof that these minerals originated in magma and were transported by gases and liquids. However, very few commercial deposits are ever formed around

these openings, although possibly just such gases and waters are even now forming mineral deposits at slight depths below the earth's surface.

Thus far, in this sequence of mineral forming processes, products of an igneous magma have been separated and deposited as valuable concentrations, and these processes have all been constructive; that is, something has been added to the region intruded. According to the definitions, these deposits are primary; and further formation of primary minerals from this particular body of magma is not possible. Now the ever-continuing process of weathering and erosion begins to form secondary mineral deposits. In regions where weathering is fairly rapid, that is, in warm or temperate climates, waters percolating downward from the surface may leach the minerals from upper portions of veins and convert them to new minerals in a process known as oxidation. This process forms an upper zone where only insoluble minerals occur, and below this a zone of minerals formed by the oxidation of the original minerals. Below the water table (the level at which water stands in the earth) is a third zone, the zone of secondary sulfide enrichment. The downward trickling water alone does not accomplish most of the oxidation and dissolving; but by solution and by reaction with certain minerals, acids and strong oxidizers are produced which greatly hasten the process. Ferric sulfate is the important reagent; consequently iron is essential in reactions which form the acids and oxidizers. For this reason, if pyrite is scanty or lacking in the original deposit, all that will happen is minerals in the vein above the water table will be changed to carbonates or oxides, without much enrichment. If iron is available, however, the dissolved minerals from upper parts of the oxidized zone may enrich the lower parts; and when the solutions reach the water table, which excludes oxygen, sulfides of the metals are precipitated.

Next in the general sequence, bedrock with its contained mineral deposits is broken down by weathering, and the products are carried away in solution or suspension. The heavy or durable minerals, however, such as gold, platinum, cassiterite, and gems, may be left behind in stream bottoms or along benches as valuable placers. The fine material that is carried away collects in the lowlands and under shallow seas to form sedimentary rocks, many of which are impregnated with potentially useful minerals, such as oxides of iron or manganese. These rocks need only leaching to become workable deposits of hematite. Even low grade silicate iron ores, which might be considered as sedimentary rocks high in iron, are being mined.

Water running off the land into shallow basins under arid conditions will, after long evaporation, deposit minerals such as salt, potash, nitrate, etc. The evaporation of sea water in bays and arms that are almost landlocked also produces these evaporite deposits.

Certain substances very resistant to solution or weathering remain behind as residues while other parts of rocks are removed. These substances sometimes accumulate in sufficient quantity to form mineral deposits, called residual deposits, which should not be confused with placers.

Finally, a class of secondary mineral deposits is formed when materials are subjected to certain types of regional metamorphism, forming minerals that are stable under stress and heat. Examples of such minerals are asbestos, graphite, talc, and garnet.

Geologists are generally agreed on the origin of secondary deposits, but the exact origin of primary deposits is still disputed. Although the hydrothermal theory of ore formation, which has just been outlined, is held by the majority, many, some of whom have devoted their lives to the study of ore deposits, believe that the theory does not satisfactorily explain many observed facts. The reader who may wish to get other sides of the issue is referred, for a theory based upon igneous melts as mineralizing agents, to *The Ore Magmas*, by J. E. Spurr, McGraw-Hill, New York; and for a theory comparing the formation of mineral deposits to blast furnace melts to *Ore Genesis*, by J. S. Brown, the Hopewell Press, Hopewell, N.J.; for the hydrothermal theory to *Mineral Deposits* by Waldemar Lindgren, McGraw-Hill, New York, and *Economic Mineral Deposits* by A. M. Bateman, John Wiley, New York.

METALLOGENETIC EPOCHS

Before taking up the origin of mineral deposits in detail, there are two concepts fundamental to prospecting that must be understood: the concepts of metallogenetic epochs and metallogenetic provinces. (Metallogenetic means "origin of metals"). A study of the ages of igneous rocks which accompany mineral deposits and of the deposits themselves, reveals that deposition has occurred mainly during certain ages or epochs, which, although they covered vast lengths of time, in the scale of geologic history are short and fairly well defined. In general, the epochs of deposition of metallic deposits coincide with those of igneous intrusion, which in turn are associated to some extent with mountain building activity. Secondary deposits formed by sedimentation or evaporation, on the other hand, were laid down during long periods of quiet, stable deposition. Deposits formed by weathering, such as placers, were formed during Tertiary and Quaternary time, although this could be only apparently so; those formed earlier may have been destroyed.

as Alaskan primary deposits are concerned, middle and late Mesozoic epochs,

and an early Tertiary epoch are the most important times of primary mineral deposit formation, but elsewhere in the world the following epochs are recognized:

Precambrian times were periods of mineral deposition all over the world, but since the Precambrian eon comprises over 75% of the earth's life, this fact is not remarkable. A few examples of mineralization of this age are the Black Hills gold, Canadian Shield deposits, and Lake Superior iron and copper.

Middle Paleozoic time was a period of weak metallization and definite sedimentary deposits, among which are the Clinton iron ores of Eastern U. S., and widespread salt deposits.

The period of mountain building at the end of the Paleozoic era was accompanied by mineralization which produced the Cornish tin, European gold and silver, and the Urals' platinum, but very few deposits in North America.

An epoch which occupied the end of the Paleozoic and beginning of the Mesozoic eras, the Permo-Triassic, was one of widespread sedimentary deposition of potash, salt, gypsum and copper. It was, as would be expected an era of aridity. Middle Mesozoic (Jurassic) time was an epoch of deposition of oolitic iron ores in Europe and England and metallization in western North America, during which time some Alaskan copper may have been deposited.

In late Mesozoic (Jurassic-Cretaceous) times, the Pacific Coast region of North America was the scene of great igneous activity, during which the Coast Range batholiths were intruded. Many gold deposits of California and Alaska were formed in this epoch, as well as were base metals on a world-wide scale.

The Early Tertiary epoch, one of the most important, began when rocks of intermediate composition, such as monzonites, were intruded into older formations. Examples of deposits formed at that time are Butte, Coeur d'Alene, Leadville, and the porphyry coppers of the southwestern states, as well as many deposits in Mexico and western South America.

In Late Tertiary times, mountain building was accompanied by deposition of gold-silver veins, notably at Comstock, Tonopah, Cripple Creek and other places in the Western United States and Mexico. Some placers of California and Australia were formed during that time.

Quaternary times saw the formation of most of Alaska's Placers.

METALLOGENETIC PROVINCES

Certain regions of the world have been the scenes of abundant mineralization of a definite type, and in many regions repeated mineralization in different epochs has produced deposits of the same metals. Such regions are metallogenetic provinces. A few of the larger provinces in North America are the Canadian Shield gold province, Lake Superior native copper province and iron province, western gold provinces and the Coeur d'Alene, Idaho, silver-lead province. The gold province of Alaska embraces most of the state excluding the Arctic slope, and a copper province occupies the Copper River-White River region. A mercury province occurs along the Kuskokwim River and in adjacent areas.

CLASSIFICATION OF MINERAL DEPOSITS

It was mentioned earlier that classifications have been devised so that facts learned from observation of one deposit can be applied to the search for and exploitation of others. Another, and at this point a more important reason for classification, is that the beginner in the study of mineral deposits can be better organized, and not become lost in a maze of details. The detailed description of mineral deposits given in this chapter is based upon such a classification so that the reader can, by referring back to the classification, easily orient the type of deposit under discussion to the whole subject. The classification which is used here is that of Alan M. Bateman, as given in his *Economic Mineral Deposits*, 1950 edition. It is based primarily upon origin, although shape of deposit and even commodity produced, are used; and it considers the deposits in the chronological sequence of formation already presented. Thus, the classification starts with the emplacement of a magmatic body, describes the magmatic concentration deposits, later primary deposits, and then moves on to the secondary types such as sedimentary and mechanically concentrated deposits. It is one of the most recent in the literature, and is widely accepted. It is used here with the permission of Dr. Bateman and the publishers.

In this classification, mineral deposits are divided into nine groups, each of which has a distinctive origin and exhibits distinct characteristics. The prospector would do well to commit these nine groups to memory. The first four groups are of primary of hypogene origin; the last five, secondary or supergene. Unfortunately, these words are not exactly synonymous. Primary may refer to a concentration of minerals in a sedimentary rock, even though sedimentary deposits are formed by destructive processes, because the sedimentary rock may be a primary source for secondary deposits such as evaporites or placers.

Classification Of Mineral Deposits
(After Bateman)

<u>Process</u>	<u>Deposits</u>	<u>Examples</u>
<u>Primary Processes</u>		
<u>Syngenetic</u>		
1. Magmatic concentration	Early magmatic Disseminated crystallization Segregation Injection	Diamond pipes of Africa Kenai Peninsula chromite
	Late Magmatic Residual liquid segregation Residual liquid injection Immiscible liquid segregation Immiscible liquid injection	Goodnews Bay platinum and chromite
<u>Epigenetic</u>		
2. Sublimation	Sublimates	Sulfur on Unalaska and Akun Is., Aleutian Is.
3. Contact metasomatism	Contact metasomatic	Magnetite and chalcopyrite at Copper Mountain, Prince of Wales Island
4. Hydrothermal processes		
Cavity filling	Fissure veins Shear zone deposits Stockworks Ladder veins Saddle-reefs Tension-crack fillings (pitches and flats) Breccia fillings Volcanic Tectonic Collapse Solution cavity fillings Caves and channels Gash veins	Fairbanks Hirst Chichagof Morning Star, Australia Bendigo, Australia Wisconsin lead and zinc
Replacement	Pore Space fillings Vesicular fillings Massive Lade fissure Disseminated	Bassick pipe, Colorado Mascot, Tennessee Zinc Bisbee, Arizona Wisc.-Illinois lead-zinc Upper Mississippi Valley lead zinc White River, Alaska, Copper Noranda, Quebec, Sulfides Kennecott Copper Lost River, Alaska tin
<u>Secondary Processes</u>		
5. Sedimentation (exclusive of evaporation)	Sedimentary iron, manganese, phosphate, etc.	Clinton Iron ores
6. Evaporation	Evaporites Marine Lake Ground water	Salt beds, United States Searles Lake, Calif. Chile nitrate

<u>Process</u>	<u>Deposits</u>	<u>Examples</u>
7. Residual and mechanical concentration		
Residual concentration	Residual deposits: Iron Manganese, bauxite, etc.	Sinuk River (Seward Peninsula), Alaska iron
Mechanical concentration	Placers Stream Beach Eluvial Eolian	Fairbanks, Alaska Nome, Alaska Dutch East Indies tin Australian gold
8. Superficial oxidation and supergene (secondary) enrichment	Oxidized supergene sulphides	Ray, Arizona copper
9. Metamorphism	Metamorphosed deposits Metamorphic deposits	Imuruk Basin, Alaska graphite

Syngenetic Primary Deposits

MAGMATIC CONCENTRATION - The only class of syngenetic deposits that occurs in igneous rocks is that of magmatic concentration. The processes of differentiation operate continuously to produce rocks of varying composition; and when one of the rocks so produced contains a valuable mineral, a magmatic concentration is formed. Deposits of this type, therefore, are portions of igneous rocks in which certain valuable minerals were concentrated before the consolidation of the magma.

The solidification of the magma takes a long time; and during the early stages, processes operate which are quite different from later ones. The first breakdown then, is based upon time of formation.

Early Magmatic Deposits - Early Magmatic deposits are divided into three types: disseminated, segregated, and injected.

Disseminated deposits contain crystals of valuable minerals scattered throughout the rock. The size of such a deposit is large in comparison with most deposits, because no concentration has taken place; and thus the entire body of rock must be removed in mining. The diamonds scattered through kimberlite rocks in South Africa volcanic pipes form disseminated deposits.

Formerly, "segregation" was used to denote almost any type of magmatic concentration deposit, but in this classification, segregated mineral deposits are those in which crystals of valuable minerals were formed early in the magma, and were concentrated by settling out, by accumulating on the borders, or by falling behind the still liquid portions of the magma during flowage. Examples of this type are the chromite deposits of the Kenai Peninsula which form horizontal layers of chromite-rich rock in dunite.

Injected mineral deposits of early magmatic origin are thought to be formed when a magmatic concentration is forced into some other host rock, probably as a mixture of crystals and magma. Further work is throwing doubt on the existence of this type of deposit and tending to attribute it to later magmatic processes.

Late Magmatic Deposits - These deposits result from the consolidation of the portion of magma which is left after early formed minerals have been removed. They are now believed to include most deposits of magmatic concentration origin and are divided into four groups.

Although in general a magma undergoing consolidation becomes more and more siliceous as the early crystallized parts are withdrawn, in certain types of basic lavas, residual magma, as the last parts to crystallize are called, becomes enriched in iron and titanium. If this remaining liquid becomes separated from the early crystals, perhaps by settling, and solidifies into a mineral deposit, it is classed as a residual liquid segregation deposit.

The titaniferous magnetite bands in the Bushveld complex in Africa are examples. Rocks commonly associated with deposits of this class are gabbro, anorthosite, norite, and like basic rocks.

If the residual liquid is subjected to squeezing or a difference in pressure so that it is forced into enclosing rocks, a residual liquid injection deposit is formed. Ore bodies of this class are of irregular shape, or in the form of dikes or sills. The titaniferous magnetite deposits of the Adirondacks are examples of this class. Most pegmatites belong to this class,

although some also belong with the residual liquid segregations. Most pegmatitic ore deposits, however, are enriched by later replacement by hydrothermal solutions rising from the same body of magma that produced the pegmatite.

It is possible for iron-nickel-copper sulfides to separate as immiscible drops from liquid magma as it cools. (Immiscible means inability to mix). If these drops settle into depressions in a magma chamber, important accumulations of sulfides could form and upon consolidation, become immiscible liquid segregation deposits. These deposits consist of local enrichments of basic igneous rocks, containing up to 20% sulfides. Typical minerals comprising these deposits are pyrrhotite, chalcopyrite, and pentlandite, with accompanying platinum, gold and silver. They occur in basic rocks. Examples are found in some of the nickel-copper sulfide deposits of South Africa, and possibly some of the marginal deposits at Sudbury, Ontario.

If an accumulation of immiscible, sulfide bearing magma is injected or squeezed into country rock, deposits of immiscible liquid injection are formed. Examples are some of the Norway nickel deposits, and possibly the Frood deposit at Sudbury.

It should be evident by now that mineral deposits formed by magmatic concentration are associated with basic and ultra-basic rocks. A simple layered magmatic concentration deposit is shown in Fig. 7-1.

Several Alaskan mineral deposits, some of which are economically important today, belong to the magmatic concentration class. Foremost among them is the Goodnews Bay Platinum deposit, which, although it occurs in the form of placers, originated in ultrabasic rock. There, several platinum bearing streams drain a central mass called Red Mountain. The core of Red Mountain is dunite (almost pure olivine), surrounded by pyroxenite, with gabbroic rock on the outer margins of the intrusive. According to Spencer (1948), this configuration is a classical type of platinum deposit; every occurrence of this kind found has contained platinum. At Goodnews Bay, insufficient work has been done to determine the type of magmatic concentration which produced the deposit; but Mertie, in U. S. Geological Survey Bull. 918 states that early crystallization and settling of olivine, accompanied by immiscible segregation of chrome-iron-platinum ores may have been the process of formation. Platinum in place has never been found, but as Mertie calculates

(from the percentage of platinum in the chromite, and the percentage of chromite in the dunite) that at a price of \$40/oz for platinum, the dunite would have a lode-value of 1¢ per ton, this fact is not surprising. Either a tremendous volume of rock has been eroded to produce the placers, or else the rock eroded was richer than the remaining rock.

When prospecting for platinum, the first action of the prospector, aside from examining all placer concentrates carefully, is to look for occurrences of ultrabasic rocks of the type listed above and then begin prospecting the creeks draining them for placer platinum. Ultrabasics are often conspicuous by the lack of vegetation on them, as at Red Mountain. It is useless to look for platinum in place, at least until the placers are prospected, although chromite, if present in place, might upon assaying prove to contain platinum. If placer platinum is present and if it came originally from a magmatic concentration, it can always be associated with ultrabasic rocks. (In syngenetic deposits there always is close association of mineral and parent rock). In this respect, platinum differs from gold and most other minerals occurring in epigenetic deposits, because these deposits need not display a close relationship to their parent igneous rock. Exceptions are epigenetic deposits of platinum occurring in South Africa, one as a contact metamorphic deposit, and one as a fissure vein. However, the probability of finding such a deposit in Alaska is very slight.

Commercial grade chromite occurs on southern Kenai Peninsula, where dunite and pyroxenite rocks outcrop. It lies in bands of rock richer in chromite than the rest of the dunite; its origin has tentatively been assigned by the U. S. Geological Survey to processes of early crystallization and sinking with flow. Deposits are found only in the dunite, which is conspicuous by the lack of vegetation.

Several magnetite deposits of magmatic concentration origin are located in Southeastern Alaska from Klukwan, north of Haines, to Ketchikan.

Other magmatic concentration deposits, so far not of commercial grade, occur in Southeastern Alaska. The most noteworthy of these are a nickel-copper body in gabbro on Admiralty Island, and others in norite on Chichagof and Yakobi Islands.



Fig. 7-1. - Layers of Segregated Chromite Ore of Magmatic Concentration Origin (Black) in Ultrabasic Rock.

Epigenetic Primary Deposits

The remainder of primary deposits initiated by igneous action are epigenetic--"formed

outside of" the parent rock. These deposits fall into the following classes: sublimation, contact metasomatic, and hydrothermal.

SUBLIMATION - The second kind of deposit in this classification is that in which the minerals are formed by sublimation. Sublimation means the process by which a substance passes directly from a solid to a gas without going through a liquid state, and sublimates are deposits of solids which have been laid down directly from the gaseous state.

The process is unimportant, except from a scientific standpoint, in that deposits formed around volcanoes and fumeroles shed much light upon the composition of hidden magmas. Some sulfur of sublimatic origin occurs in the Aleutian Islands, and at different volcanic localities common salt in small quantities is recovered.

CONTACT METASOMATISM - (As indicated, "metamorphism" applies to the changes in an intruded rock due simply to heat; "metasomatism" includes the effect of introduction of new material).

The class of deposits formed by contact metasomatism is large and important, although prospecting and mining of individual deposits involves a large risk due to their unpredictable sizes and shapes.

When a body of magma invades an area in the earth's crust, some effect on the invaded rocks is bound to ensue. Depending on a number of factors, this change may be a slight baking for a few inches beyond the contact, or, on the other hand, the country rock may be intensely recrystallized and changed in composition, due to addition of material in gaseous form. The altered area is known as the aureole, or halo, and if valuable minerals occur in it, a contact metasomatic deposit results. See Fig. 7-2.

Much depends upon the size of the intrusive body. As heat and transfer of material are the agents producing contact metasomatism, the greater the amount of heat and transferable material stored in the intrusive, the greater the effect on the country rock. The amounts of heat and transferable material available are directly proportional to size, other things being equal. A small dike may produce hardly any effect but a batholith may have a halo several thousand feet thick; most contact metasomatic deposits are associated with stocks and small batholiths.

The depth of intrusion also influences the metamorphism. Lavas extruded at the surface produce a negligible amount of baking. Intrusive rocks produce greater changes; their cover tends to confine the heat and emanating material, so they produce a maximum amount of alteration. All of the contact metasomatic deposits investigated to determine depth of formation, appear to have formed at depths of 3000 feet or greater.

The composition of the intrusive rock affects the type of metamorphism, for, although most intrusive rocks produce some amount of contact metamorphism, most mineral deposits are associated with intrusives of intermediate acidic rocks, such as monzonite and quartz-diorite. Very acidic rocks, such as granite, and basic rocks, like gabbro, seldom produce contact metamorphic deposits. Ultrabasic rocks have never been known to produce contact metamorphic deposits. One reason advanced for this association is that minerals are mainly transported by gaseous emanations, chiefly water, and that acidic magmas contain more water than do basic ones. The lack of mineral deposits around highly acidic rocks must depend upon some other factor.

The composition of the invaded rocks is one of the most important factors which determines the degree of metamorphism. Certain porous rocks provide easier paths for emanations, but porosity is not the only influencing condition. In order to undergo intense metamorphism, the host rock must be composed of minerals which react readily with introduced substances. Limestone and dolomite meet these requirements very well; and if they contain impurities, conditions are even more favorable, since the impurities will enter into reactions to form a greater variety of new minerals. Sandstones and shales, unless they contain much carbonaceous material, are merely hardened; and metamorphic rocks are hardly affected, since they have already been changed to meet conditions similar to those imposed during contact metamorphism. Igneous rocks are likewise little affected unless their composition differs greatly from that of the invading rocks.

The structure of the invaded rocks controls the position and size of the halo to some extent. As mineralizing emanations rise, any faults near the top, or bedding planes dipping toward the intrusive, provide avenues along which the hot gases may travel for relatively great distances. These channel ways often are the seats of mineral deposits. An irregular shape to the upper part of the intrusive is favorable, because portions of the country

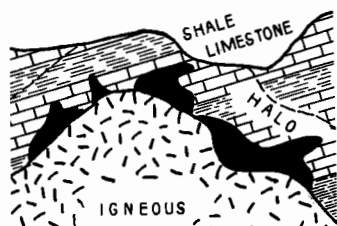


Fig. 7-2. - Contact Metasomatic Deposit (Ore is Black).

rock extending into the intrusive (roof pendants) undergo concentrated metamorphism, and likewise protruberances of the invading rock tend to localize the contact effects. A gentle dip to the contact likewise causes the metamorphism to be more widespread, as regions a long way from the outcrop on the ground may be actually only a short distance from it vertically.

Deposits of this class always occur within the halo and usually within a hundred yards of the contact; however examples are known, when favorable structure exists, of their occurrence 2000 feet away. In general, contact metasomatic deposits are small compared with other types, although several may be grouped around one intrusive.

Gangue in these deposits is composed of "high temperature minerals", or those formed under high temperature conditions. The group includes such minerals as tremolite, actinolite, epidote, chlorite, mica, and calcite, which taken together form skarn. Although a wide variety of ores are produced, those of copper and iron predominate, and of these, the minerals magnetite, chalcopyrite, and bornite are most common. Other ores are those of tin, lead, zinc, tungsten, molybdenum, graphite, manganese, emery, garnet, corundum, and gold.

The iron-copper bodies of Prince of Wales Island near Ketchikan are classical examples of contact metasomatic deposits. There the most important deposits contain chalcopyrite and magnetite with epidote and calcite around intrusions of granite, granodiorite, diorite, and syenite.

HYDROTHERMAL PROCESSES - Hydrothermal mineral deposits are formed from material transported in solution by hot water. Opinion is divided as to whether the waters spring from the parent magma as liquid, or first pass through a gaseous stage, becoming liquid through condensation and mingling with surface (meteoric) waters.

There are two processes operating to form hydrothermal deposits; cavity filling and replacement. They may operate separately or together, and often produce deposits difficult to distinguish between. These processes will be considered separately, but first it is necessary to define three terms often met in any discussion of hydrothermal deposits: hypothermal, mesothermal, and epithermal.

Hypothermal describes a hydrothermal deposit formed at high temperature, nearest the intrusive. Mesothermal indicates ore formed at intermediate temperatures and distances; and epithermal, ore at low temperature and greatest distance from the intrusive. These deposits are usually thought of as being formed at deep, intermediate, and shallow depths.

The type of mineral formed is influenced by the temperature of formation. Thus, there are certain "high temperature minerals", and "low temperature minerals". These minerals are "semi-diagnostic", that is, the presence of one of them is not enough to put a deposit into a particular temperature group, but the presence of several constitutes strong evidence of the temperature of formation. The following table (after Bateman) indicates a few of the minerals in each temperature range:

High Temperature	Intermediate Temperature	Low Temperature
Magnetite	Chalcopyrite	Stibnite
Specular hematite	Arsenopyrite	Realgar
Pyrrhotite	Galena	Cinnabar
Tourmaline	Sphalerite	Tellurides
Cassiterite	Tetrahedrite	Selenides
Garnet		Argentite
Pyroxene		Ruby Silver
Ambibole		Marcasite
Topoz		Adularia (form of orthoclase)
		Rhodochrosite
		Siderite

The structure of the deposit, as well as the mineralogy, is influenced by depth of formation. As open cavities can exist only at shallow depths, veins and other deposits of cavity filling origin usually are epithermal. Mesothermal and hypothermal deposits are formed dominantly by replacement processes. Epithermal veins exhibit less continuity than mesothermal or hypothermal deposits. These observations, like most others in the field of mineral deposits, indicate tendencies rather than rules.

Cavity Filling- The filling of open spaces by gangue and ore minerals deposited from circulating solutions is responsible for more mineral deposits than any other process, although replacement probably has produced more mineral wealth. So widespread is cavity filling that its commonest form, the filled fissure vein, is considered the typical mineral deposit. Water containing dissolved minerals percolating through openings in the rock gradually, by deposition of dissolved material, builds up a solid filling of gangue and ore minerals. Eventually this deposit may completely fill the cavity, leaving as evidence that an open space once existed only joints in the center where crystals growing inward from the walls finally touch each other. Such rows of inward pointing crystals grown together give the filling a peculiar pattern called a comb structure; and openings left in the deposit, usually containing well developed crystals, are termed vugs. Most of the filling material is quartz, although in cavity-filled deposits there

are usually two or three gangue minerals; calcite and other carbonates frequently make up a large part of the gangue. Successive layers of these unlike gangue minerals and sulfides may produce a structure called *crustification*, and often these crusts surround fragments of earlier formed ore as centers, forming *cockade ore*. If no diagnostic structure is visible in the deposit, and the vein filling is homogeneous, it is said to be *massive*. If the deposit (in the case of a fissure vein) consists of layers of quartz separated by layers of altered wall rock, *ribbon structure* results.

Ordinarily a certain amount of replacement accompanies the cavity filling process, and deposits exist in which the two processes contribute about equally to the formation of the vein.

The subdivision of filled cavity deposits is based upon origin and shape of the original opening. Some of the different types are unimportant except locally, but many of them are so widespread that they are accepted as representative types of lode deposits.

The first group consists of *fissure veins*, which originate by the filling of more or less tabular openings, formed by faulting within the earth. The walls may have been further spread during deposition by solutions under pressure entering the opening, or by the force of crystallization, although this has by no means been proved. Relative movement of opposite walls of a curved fault is enough to explain open spaces alternating with tightly closed areas. Several different kinds of fissure veins are recognized, called *simple*, *composite*, *sheeted*, *linked*, *dilated* or *lenticular*, and *chambered*.

Simple fissure veins are tabular fillings of a single fissure whose walls are more or less straight and parallel.

Composite veins or *lodes*, are large zones of approximately parallel fissure veins with connecting diagonals. The intervening country rock has undergone some replacement.

Sheeted zones consist of systems of closely spaced parallel small veins. The veinlets are not connected and the intervening rock is barren.

Linked veins are sheeted zones in which individual veinlets are connected by cross veinlets.

Dilation veins, or *lenticular veins*, are veins that consist of a series of alternate bulges and pinches; sometimes the bulges or lenses are disconnected due to subsequent rock movement and are called *en echelon veins*.

A *chambered vein* is a simple fissure vein which has irregular chambers along its walls due to its being formed near the surface, where the light pressure exerted by overlying rock was insufficient to keep the walls from bulging and shattering.

Fissure veins may dip at any angle, although most are highly inclined. Steeper ones are easier to mine because broken ore flows easier in them. They all curve to some extent and, as a consequence, alternately widen and narrow ("swell or pinch") because fault movement along a curved surface tends to produce openings varying in width. All but exactly vertical veins form curved intersections with a hilly ground surface.

Fissure veins range in length from a few hundred feet, the most common, to several miles. Very long ones usually are barren, as are very wide ones. (The Comstock Lode, Nevada, several hundred feet wide, and three miles long, is a well known exception). The fault displacement is ordinarily small. Wall rocks are commonly altered by the formation of *sericite*, *pyrite*, *silica*, *chlorite*, or other products of hydrothermal alteration, and the alteration may extend outward from a few inches to several feet. Often, *fault gouge* or *selvage*, a claylike substance formed by pulverization along the fault accompanies the ore. *Gouge* may also be partly due to hydrothermal alterations.

A fissure vein may undergo several stages of mineralization, with intervening movement and widening of the fissures. Different systems of veins, each occupying a group of faults having similar directions, dips, or ages, often occur in mineralized districts.

The type of country rock in which the fissures occur has a great influence on shape and size of the vein. A tough rock tends to develop regular "strong" fissures which, upon passing into a brittle rock, split into sheets and linked veins, or, upon passing through a dike, become narrow. The chemical composition of the wall rocks also influences the vein, insofar as some rocks are more favorable to deposition than others.

For obvious economic reasons, how far the vein will extend is a subject of endless speculation. Termination lengthwise may be due to gradual narrowing of the original opening. It may also be due to the vein passing into a different rock, shattering and *finger*ing out; or the fissure may be terminated by a dike. The relation of depth to length depends upon how much of the vein has already been eroded away; but in general the depth will be less than the length, and a rule of thumb followed by some, states that the depth will be about one half of the length.

Some of the most important mining districts in the world owe their existence to fissure veins, and almost every type of metal except iron is produced from them. A very few examples are: gold: Cripple Creek, Colorado; Mother Lode, California; Porcupine, Ontario-silver: Potosi, Bolivia-silver-lead: Freiberg, Germany-copper-zinc: Butte, Montana-tin: Cornwall, England-antimony: Hunan, China-cobalt: Ontario-mercury: New Idria, California-radium: Great Bear Lake, Canada.

Shear zones are zones from one to a hundred feet across, which consist of innumerable

small shears instead of one or two faults. They are very good conductors of waters, but in general, favor replacement rather than filling. The openings are so minute that very rich fillings are necessary to make them mineable.

Stockworks are masses of rock containing networks of veinlets, which individually are usually not more than an inch wide and a few feet long. The rock between veinlets may or may not be impregnated with ore minerals; in either case, the entire stockwork must be mined. Stockworks often accompany veins and replacement deposits, but sometimes occur as separate bodies. As a rule they are low grade, because intervening country rock must be mined, but large tonnages are available. The fissures are formed by contraction of outer portions of intrusive rocks upon cooling, and by shearing such as produces shear zones. Stockworks are mined at Altenberg, Germany and Cornwall, England, for tin. At Juneau, Alaska, a tremendous stockwork was mined for gold. There, disseminated replacement was partially responsible for the deposit.

When alternating beds of brittle and soft rocks are closely folded, curved open spaces may be formed at crests of the folds; if these are filled with vein material, they form saddle reefs. The reefs are repeated in bed after bed and may extend along the fold axis for thousands of feet. At Bendigo, Australia, gold is mined from saddle reefs, one of which extends 4600 feet vertically and 9000 feet horizontally.

Short cross veins in dikes are called ladder veins because they roughly resemble the rungs of a ladder. They are caused by filling of joints in dikes formed either by contraction or movement. The veins are mined separately or the whole dike is removed. Examples are found at Victoria, Australia (gold); New South Wales (molybdenite); and Telemarken, Norway (copper).

Close to the surface, where pressure of overlying rock is fairly light, slight warping or slumping of brittle sedimentary rocks forms a series of connected cracks known as pitches and flats, and at the crest of folds, tension cracks. The best known examples of pitches and flats occur in the Upper Mississippi Valley in the lead-zinc district. In this area, slumping of limestone produced cavities partly filled with lead-zinc minerals, the mineralized areas being on the order of 75 feet wide, 50 feet high, and 1000 feet long. Wedge-shaped tension cracks at the crests of folds are sometimes fairly long, but their vertical extent is limited.

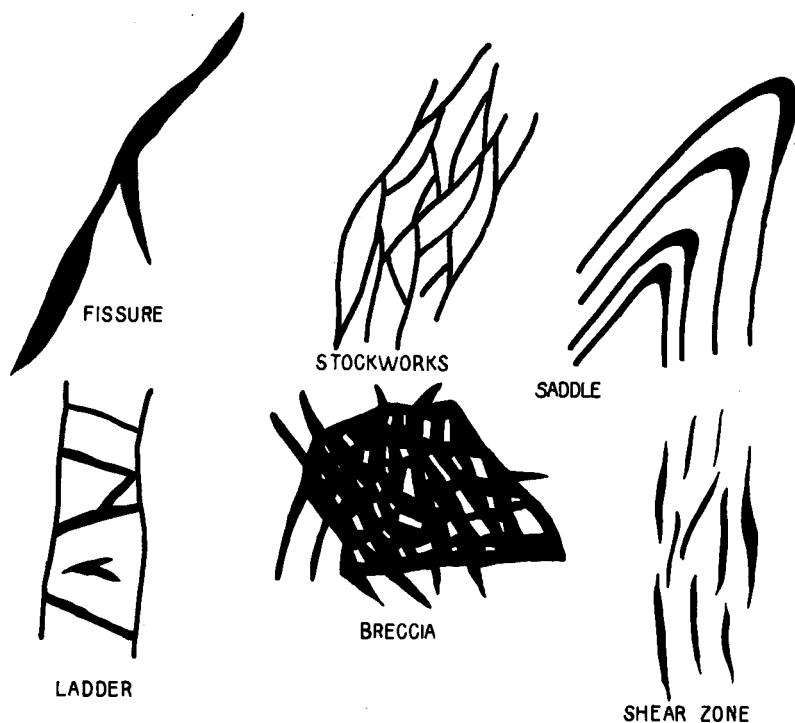


Fig. 7-3 - Types of Cavity Fillings

Caves and other solution cavities form in soluble rocks where water has dissolved and transported material away. They take the form of long river-like openings, round or irregular massive openings, or gashes between joints. These openings are seldom solidly filled, although often ores form as crusts or as solid masses filling the bottoms to form solution cavity fillings.

Breccias are masses of angular rock fragments which have been cemented. Before complete cementation they provide plenty of space for mineral deposition, and cementation by valuable minerals produces breccia filling deposits. The breccias are formed originally by volcanic action, collapse of underlying formation, or shattering of rocks in a region due to stresses in the earth. Breccias must be confined before they are particularly receptive to ore formation; without confining walls, circulation is insufficient. Volcanic breccia mineral deposits usually occupy volcanic necks, which give rise to roughly circular pipes which have great vertical extent compared to their diameters. Several volcanic pipes have been mined at San Juan, Colorado, and the Braden Copper deposit of Chile is held to be formed in a volcanic pipe. Collapse breccias are formed when a solution opening is formed at depth. The roof begins caving, and continues to cave, until a cylindrical mass of broken rock having the solution cavity at the bottom has been formed. Percolating solutions flowing through the mass gradually fill the spaces, forming a mineralized pipe. Examples are the southwest pipe at Bisbee, Arizona, the Cactus pipe in Utah, and several at Sonora, Mexico. Shatter breccia is formed in brittle rocks by earth movement; ores have been formed in them in the Tri-State zinc region.

Porous rocks, such as sandstone and limestone, sometimes have their pores filled with deposits to form pore space fillings. Porosity is not the only factor affecting deposition of this type, however; the rock must be permeable. Rocks such as sandstones composed of coarse particles are more permeable than, for example, mudstones composed of fine particles, even though the fine rocks contain more pore space. Deposits formed by filling of pore spaces occur in the southwest states, where copper minerals fill sandstone pores to form the so-called "red beds". Vanadium, uranium, and radium occur in sandstones in western Colorado and Utah. Mercury ores are found in California sandstones. Oil and gas are found filling porous rocks all over the world.

When lavas are extruded, the release in pressure allows dissolved gases to expand, forming innumerable holes or vesicles, especially near the upper edge of the flow. When these vesicles are filled, they are called amygdules, and when filled with valuable minerals, they may form vesicular filling ore deposits. Native copper filling of vesicles in lava of the Lake Superior region has produced ores, but elsewhere they are not at present commercially valuable. Extensive copper vesicular deposits occur in the White River district of Alaska and Yukon territory. Some of the filled cavities discussed above are illustrated in Fig. 7-3.

Metasomatic replacement- Metasomatic replacement is a process whereby one mineral is dissolved, an infinitesimal part at a time, and the infinitesimal space created is filled immediately by an equal volume of a new mineral. The new material is deposited from the same solution that dissolved the old one. The term "metasomatic replacement" is often supplanted with "metasomatism", meaning "change of body", or simply by "replacement".

This process is the most widespread and economically important of all. Many processes such as contact metasomatism and secondary sulfide enrichment, which are grouped as separate modes of formation, are really only special types of replacement.

The replacement solutions may be gaseous or liquid; in either state water is the main constituent. The solutions are of magmatic origin, but may acquire additional meteoric water and dissolved minerals from rocks which they traverse.

Because the ores are deposited by replacement, fissures or other openings are not necessary for deposition, but of course such openings, including microscopic cracks, are necessary for transporting solutions to regions where replacement is taking place. In most instances the ore can be seen to be localized around initial openings in the country rock. Replacement starts next to the opening, for instance a fault fissure, and replaces the walls first, then continues into the wall rock. Apparently the solutions have to pass through a thicker and thicker layer of already replaced material, which is impossible. Careful microscopic study has revealed that the solutions take advantage of every minute fracture or pore space to penetrate as far as possible; then the replacing mineral completes its journey by diffusion, a slow molecule by molecule migration. The dissolved and replaced mineral leaves by the same process.

Thus, obviously a shattered and permeable rock provides a better host for replacement than an impermeable one, but of at least equal importance is the chemical composition of the host rock. Innumerable examples occur where mineralizing solutions pass up one rock or mineral and completely replace another; the reasons are usually obscure or unknown. This selection accounts for so-called "selective replacement", in which certain parts of a rock are replaced, resulting in a disseminated ore body, with the valuable minerals scattered uniformly through the gangue.

The higher the temperature and pressure of the circulating solutions, the more intense is the replacement. At normal surface temperatures some limestones are replaced and secondary sulfide enrichment occurs; at slightly higher temperatures some sulfides may be deposited in fine

grained small masses. With increasing temperature, wholesale replacement of rock ensues, and large ore bodies are produced. At very high temperatures almost any rock will be replaced, and minerals of contact metamorphism may develop. Many tin and tungsten deposits are high temperature replacements. Minerals which have already replaced other minerals may themselves be replaced by a third, and the third by another, continuing sometimes for eight or ten successive stages. Commonly, the sequence of replacement follows a fixed order: pyrite, enargite, tetra-hedrite, sphalerite, chalcocite, bornite, galena, ruby-silver.

Replacement may be recognized by several criteria, some of which may be observed in the ore in place; some in hand specimens with the naked eye or simple hand lens, and some under the microscope. Some of the most important are enumerated: 1. If remnants of the wall rock are imbedded unsupported in the ore, especially if they exhibit features (such as schistosity) which line up with the country rock, replacement is indicated. These inclusions, called horses, are easy to see in the field. 2. If original structure (of replaced material) is preserved in the ore mineral, replacement is definitely indicated. The best known example of this criterion is the replacement of wood by silica, in which the cell structure of the wood is preserved, but stratification, crystal structure, and other forms observed in rocks may be preserved. 3. Crystals of material foreign to the country rock indicate replacement, if they cut and completely interrupt the bedding or other features of the rock. These crystals are differentiated from those formed by pushing the rock apart during crystallization, which are recognized by the bedding being bent around the crystal. 4. A crystal of the composition of one mineral and the crystal form of another (a pseudomorph) definitely indicates replacement. 5. Small wavy irregular veinlets of a mineral cutting across several different minerals usually are caused by replacement. (This is more often determined through a microscope). 6. An extremely irregular form of deposit is a good criterion of replacement, but other indications should be sought also.

There are three types of hydrothermal replacement deposits, based upon form. Massive deposits are bodies in which solid ore extends to the limits of replacement. They vary so much in size and shape that no typical ones may be chosen. The most spectacular, like those at Flin Flon or Noranda, Canada, are huge masses of sulfides that contain copper, zinc, gold and silver. The ore body at Flin Flon is 2600 feet long at the surface, and up to 400 feet wide.

Lode fissure deposits are more or less tabular, like fissure veins formed by cavity filling, but are generally wider, and have irregular boundaries and often scattered outlying centers of mineralization. The Kennecott Copper veins are of this type, as are the Kirkland Lake, Ontario, gold deposits, and the Coeur d'Alene Idaho, lead zinc lodes.

Disseminated replacements consist of scattered centers without any solid mass of ore. They are represented by the "porphyry" coppers of the southwestern United States (called "porphyry" incorrectly because the ore minerals are scattered through the rock like phenocrysts). The copper belt of northern Rhodesia, and the molybdenum of Climax, Colorado, are other examples.

The three simple types just mentioned occur in more or less homogeneous rocks. Where structure controls deposition, a number of different shaped ore bodies may be formed. Single fissures may initiate replacement to produce tabular replacement veins or lodes. A fissured region or shear zone may become an irregular disjointed system of lenses and sheets, separated by remnants of the country rock, as at the Alaska Juneau mine. Where fissures intersect, enlargements of the veins may occur. Roughly cylindrical pipes may form in volcanic necks or in any enlargement, such as an intersection of fissures. Close folding shatters the country rock, forming receptive areas for replacement; any breccias are also very favorable sites for massive replacement. Bedding planes or especially permeable beds in sediments may become horizontal tabular replacement deposits.

Ore Shoots - Ore shoots are portions of a vein that are richer than others; as their name implies, they contain the economically recoverable material. The term is used only for primary ore. Ore shoots are irregular in shape but generally the vertical dimension is greater than the longitudinal. Several different factors influence the deposition of minerals in ore shoots, but many shoots cannot be correlated with any other feature in the vein. Those factors which are recognized as affecting the location of ore shoots are as follows:

Open spaces provide room for deposition. Intersections of veins are often the seats of ore shoots. Impounding of mineralizing solutions where they meet impermeable layers in ore shoots. Wall-controlled shoots occur where the wall rock is favorable chemically to deposition. Structure of the fault and the country rock controls deposition. Changes in dip or strike, alternating beds, folds, etc., may be the controlling factor. Depth control is exerted upon ore shoots because of the effect of temperature and pressure upon deposition.

Recurrent mineralization shoots are formed by the recurrent movement of the fault along which the vein is forming, opening the vein again. New mineralizing solutions entering the vein tend to deposit rich shoots, usually against a wall.

SEDIMENTATION - Sedimentary mineral deposits, like magmatic concentration deposits in igneous rocks, are simply rocks that contain a large proportion of some desired mineral. For this reason, as previously noted, sedimentary mineral deposits are sometimes referred to as primary and syngenetic.

Sedimentation takes place in several different types of basins; among them are bogs and lakes, swamps, peneplane depressions, shallow seas, and open seas. However, four factors are necessary for the formation of a sedimentary deposit, and the resulting deposit depends to some extent upon all four. These factors are an adequate source of material, solution or erosion to liberate the material, a transporting medium (except for coal), and finally a basin of accumulation.

Probably the best way to illustrate the process of sedimentary accumulation of mineral deposits is to discuss briefly the most important sedimentary products and their modes of formation. The valuable constituents of these deposits must be liberated from rock, gathered together, transported, and deposited. The sedimentary rocks containing these constituents are then available to furnish material for new sedimentary deposits. For this reason the process is called a cycle; thus there is the iron cycle, the manganese cycle, etc.

Iron is the fourth most abundant element in the earth's crust; the ordinary basic rocks provide an ample supply to form sedimentary deposits of iron ores. During the natural course of weathering, iron is dissolved in water containing carbon dioxide, organic acids, or sulfate solutions. The dissolved iron is transported in streams and rivers and as long as no great change in the water occurs, chemically or physically (traversing limestone causes iron to be precipitated as a carbonate or oxide), it will remain in solution until it reaches some basin. Here it is removed from solution by various means, including bacterial action.

If it reaches a lake or bog, it will be deposited as limonite or siderite, which may oxidize to hematite. The deposit, of course, will be small and local. If the dissolved iron comes to rest in a swampy basin where heavy vegetation is growing, the carbonate, siderite, is deposited; the iron beds formed in swamps often are associated with coal formed from the vegetation. This mixture of coal and iron is called black band iron ore. If no coal is present and the iron is mixed with clay, it is called clay ironstone.

Tremendous amounts of iron silicates have been laid down in the open oceans, and sedimentary rocks containing much iron have been formed there. It is not proved, however, that any commercial deposits have been so produced, although some hold the Lake Superior iron to have been deposited in oceans.

Shallow, nearly land-locked seas have been the seats of deposition of most of the important iron deposits of the world. Sluggish streams carrying dissolved material and very little suspended material bring the iron to the sea; consequently the resulting deposit contains little sediment. The Clinton iron ores of East Central United States extending from Wisconsin to Alabama and east to New York had such an origin. At Birmingham, Alabama, they are the basis of a great steel industry. The ore occurs in several beds of great lateral extent; the thickest bed is thirty feet thick in places. Leaching near the outcrop has produced ore of fifty to sixty per cent iron, but unleached ore averages thirty five to forty per cent.

Iron of the Lake Superior region was laid down originally in extensive beds of iron silicates, carbonates and oxides. Subsequent leaching near the outcrops formed hematite ore containing over fifty per cent iron. A new industry, based on concentration of the unleached ore, which contains about thirty per cent iron is beginning in the region. The primary source of the iron, before sedimentation, is thought to have been basic lavas.

Sedimentary Manganese is deposited under conditions similar to those under which iron is produced. In many places the two occur together; in most deposits, however, the greater solubility of manganese compounds allows them to be carried farther, effecting a separation. There is much less manganese than iron in the world, and sedimentary manganese deposits are naturally much smaller. Sedimentary manganese deposits in bogs and lakes, although widespread, are small; and few of commercial value exist. The product is "wad," a mixture of impure manganese hydrous oxides. Deposits of manganese mixed with coal may accumulate in swampy basins; and when the carbonate beds formed in them are enriched by leaching, economically recoverable ores may result.

The shallow sea deposits provide the greatest beds of sedimentary manganese carbonates, and oxides a few feet in thickness are widespread, but not of economic grade. Sedimentary oxides containing over fifty per cent manganese are mined in Russia, but here again, enrichment by leaching may have been effective.

Phosphates, used in fertilizers and metallurgy, occur as extensive beds in Western United States and Canada, where billions of tons are in reserve. The phosphates are liberated from phosphorus-bearing rocks and dissolved by waters containing carbon dioxide or organic matter. Some phosphates are transported to the sea and precipitated chemically, and some are concentrated in animal bones or shells which subsequently become part of the phosphate rock. In Florida, where phosphatic sedimentary rocks have been eroded and reworked by the sea, extensive beds of phosphatic pebbles have accumulated.

Sulfur is derived from sulfates and sulfides abundantly distributed in rocks. It is also supplied by the hydrogen sulfide of volcanic origin and that produced by bacterial processes.

It is transported in solution as compounds of sulfur. Reducing conditions, absence of oxygen and presence of organic material, convert the compounds to hydrogen sulfide, which is oxidized to sulfur and water. During temporary cessation of deposition of other substances, beds of pure sulfur are laid down.

Sedimentary copper beds are rare. No commercial deposits of undoubted sedimentary origin exist. Some believe that the Kupferschiefer, upon which Germany bases her copper industry, is a sedimentary deposit; others consider it hydrothermal. If it is sedimentary, copper minerals were brought in solution to the muddy bottom of a shallow sea, along with minerals of iron, lead, zinc, and many others.

Sedimentary uranium and vanadium occur as carnotite in sandstones of Cretaceous age along with petrified logs and other vegetation and bones of reptiles. The uranium and vanadium minerals are believed to have been brought to a very shallow sea in solution by streams, to have been precipitated by the vegetable material, and finally to have replaced the logs and become distributed through the sandstone around them. Here again, an alternative theory of hydrothermal origin is proposed by many.

Carbonates include limestones which are water-laid sedimentary rocks of predominantly calcium carbonate composition and dolomites, which contain magnesium as well as calcium; both may contain impurities. Limestone is deposited in a number of ways: from calcareous shells, from solution, or from suspension. It is dissolved easily by water containing carbon dioxide, and is deposited upon the loss of the carbon dioxide. Tremendous amounts are used for fluxing in iron production, and in manufacturing cement and plaster. Limestone suitable for fluxing exists in Southeastern Alaska. Cement limestone need not be pure; that containing certain combinations of impurities is better.

Magnesite, the carbonate of magnesium, occurs in sedimentary beds with salt and gypsum and is used in cements and for refractory materials.

Sedimentary clay deposits are known, although most clay is formed by residual processes. Clay is carried in streams as a very fine suspension (unlike the other sedimentary products, which are carried in solution) and deposited offshore and in shallow embayments of the sea, in lakes and swamps, and along streams. It often grades laterally into silts and sand. Fire clay is a very fine refractory clay that underlies coal seams. The presence of coal indicates that the fire clay was laid down under very stagnant conditions.

Bentonite is water-laid or air-laid clay formed by the alteration of volcanic ash.

Earths and Sands include diatomaceous earth, which is used as a filter. It is formed by the accumulation of remains of diatoms, microscopic organisms which live in fresh or sea water. Fuller's earth, used for cleaning and absorbing, consists of naturally absorbent clay. It occurs with sands and ordinary clays.

Sand and sandstone are used for building material, molding sand, sharpening stones, glass making, etc. Each use requires a different quality; the quality itself depends upon the combination of source material and grain size during sedimentation.

Coal is derived from vegetable matter, and is, therefore, a sedimentary rock of organic origin. The higher rank coals have undergone metamorphism, but nevertheless, originated as sedimentary rocks. The organic constituents of coal are furnished by plants growing in fresh water swamps under conditions favorable to the growth of lush vegetation, that is, a warm humid climate. The minerals that furnish food for plants are transported to the organism by water, just as lime or phosphate is brought to certain shelled animals and converted by them to mineral deposits. As plants flourish and die, they begin to decay; but the stagnant water into which they sink soon attains an equilibrium between the bacteria which cause decay and a toxic material which prevents decay beyond a certain limit. If the water remains sufficiently deep to cover the dead vegetation that has fallen, and yet shallow enough to allow plants to continue growing, vegetation begins to accumulate. If the swamp gradually subsides, great thicknesses accumulate into peat. If conditions then change and other sediments cover the peat, eventually creating uniform pressure and heat, chemical changes and compaction produce coal.

There are three main ranks of coal, formed by increasing degrees of metamorphism: lignite, bituminous and anthracite. Folding of the beds hastens the process, producing a higher rank of coal in a shorter time. Alaskan coals are Carboniferous-Cretaceous, or Tertiary in age; most are "subbituminous" in rank, yet metamorphism has raised some to the rank of anthracite.

It is believed that all coal so far known in the world was laid down under temperate or sub-tropical conditions. Today peat is accumulating in cold temperate and arctic regions; it is not known whether it can eventually become coal.

Oil and Oil Shale were formed by minute plants and animals living in the shallow seas of past ages. As the organic remains accumulated in the bottom mud, bacteria produced changes which converted the remains to a substance which may be called the "mother" of oil. After that the process is unknown; either this mother of oil was further changed by bacteria before deep burial, or upon burial a distillation process produced oil. The oil, when collected within porous formations and overlain by impermeable rocks with a structure which can trap it, forms a pool, and may be recovered by tapping the porous formation and either drawing off the oil under natural gas pressure or pumping it out. Oil shale, shale impregnated with

bituminous matter, yields petroleum upon heating. Some shale yields up to forty gallons per ton; but its utilization is not yet commercially feasible.

EVAPORATION - The precipitation of minerals through evaporation of water has produced another class of ore deposits, namely evaporites. For convenience, evaporite deposits have been divided into four classes; those precipitated from sea water, from lake water, from ground water, and from hot springs. Although evaporation is a simple process, it has produced some deposits very difficult to explain.

Ocean waters - Ocean water contains a fixed content of salts, about 3.5% by weight, including, in order of abundance, sodium chloride, magnesium chloride and magnesium sulfate, calcium sulfate, and salts containing potassium, iodine, bromine, iron and others. If a body of seawater is cut off in an arid region, evaporation ensues. When its volume has shrunk to about half, iron oxide and calcium carbonate are deposited; when it shrinks to one fifth, gypsum or anhydrite are deposited; and when it shrinks to one tenth, common salt is deposited. Where a body of water is cut off completely and totally evaporated, all salts present in the water are precipitated; but where additional water flows in, bringing fresh salts, the first ones to be precipitated sink and build up thick layers. It is believed that at various times in the past sea water has been partially evaporated, to yield, for instance, gypsum; then the basin has been tilted by earth warping and the concentrated liquor decanted off, after which evaporation has continued to produce common salt beds. Only in this way can separate deposits be explained. Beds of gypsum, anhydrite, common salt, potash, borates and bromides have been formed by evaporation of ocean waters. One of the greatest deposits of this type, at Stassfurt, Germany, has produced a great variety of salts.

Lake waters - Lakes, being smaller than the sea and deriving their mineral content from small catchment basins, exhibit wider ranges in composition. In exceptionally rainy years the concentration of salts in lakes decreases, and in dry years it increases resulting in deposition. Salt lakes, with miles of common salt around their edges, are fairly common in all arid countries; the Great Salt Lake of Utah and the Dead Sea of Palestine are examples. Alkali and bitter lakes yield sodium carbonate and sodium sulfate, and others yield borates, potash, and nitrates.

Ground water - In arid regions, even evaporation of ground water may form mineral deposits. Nitrate deposits of the east slope of the Andes in Chile and a few lime deposits were formed in this way.

Hot Springs - Evaporation of waters at orifices of hot springs has produced many interesting deposits, but few of commercial value.

RESIDUAL AND MECHANICAL CONCENTRATION - The weathering of rock produces the seventh class of mineral deposits, which are found in the mantle rather than the consolidated rock. If the deposit accumulates in place, it is residual; if transported, it is mechanical.

Residual Concentration - Residual deposits are those that accumulate as the result of weathering and removal of soluble parts, leaving insoluble residue behind to form, eventually, an ore deposit. The four requirements for residual deposition are rocks containing the valuable material, a climate favorable to chemical decomposition, low relief so that the residue is not washed away, and a long period of crustal stability.

Two general kinds of residual deposits exist: that in which the residue is the same mineral which was disseminated through the original rock, and that in which a new mineral is formed during the weathering process which then accumulates into a deposit. Residual gold placers are examples of the first type; deposits of bauxite, the ore of aluminum, are examples of the second.

There is an important difference between weathering in the temperate zones and in the tropics. In temperate regions, aluminous rocks decay to form soils rich in clays-hydrous silicates of aluminum, because the silica is not dissolved. In the tropics and sub-tropics, however, rock decay goes further and much of the silica is removed. The resulting soil is called laterite, composed partly of hydrous aluminum oxide, or bauxite. If soils happen to be rich enough in clay or in bauxite, they may form commercial deposits. Iron oxide is often an important constituent of laterite soils and sometimes forms important concentrations.

Many agents are effective in weathering, most of them flourishing under warm conditions. Water, oxygen, carbon dioxide, various acids formed from constituents of rocks, living forms, and heat, all contribute to decomposition. Carbonate rocks are very susceptible to weathering; quartzites very little. Silicates (except quartz) break down to soluble and insoluble constituents. Aluminum silicates and iron and manganese oxides remain. (Under tropical conditions, as noted, aluminum silicates are broken down). Magnetite remains; pyrite weathers to limonite and sulfuric acid, which further aids weathering.

As would be expected, residual concentration is most common in warm climates; it is especially uncommon in glaciated country, where glacial scouring has removed or disturbed most of the mantle, and insufficient time has elapsed since the ice age for new ones to develop. Residual deposits are, therefore, uncommon in Alaska.

The process of weathering and residual accumulation varies greatly with the material. The formation of residual deposits of a few of the most important minerals is described below.

Iron is the most important residual ore. (Lake Superior iron ores are residual concentrations

of original sedimentary deposits.) As noted previously, a warm climate is necessary for the formation of rich residual iron formations lacking silica; weathering under temperate conditions produces low grade iron concentrations high in silica. Iron-bearing limestone, ferruginous chert, and basic igneous rocks are the chief sources of residual iron ores. Massive sulfide lodes yield bodies of small use locally, and iron carbonate bodies sometimes weather to important deposits. Iron bearing silicate rock which supplied the iron for residual concentration in the Lake Superior region is called taconite; in a more general sense, any ferruginous cherts are collectively, taconite.

The most important deposits of manganese are residual. Although manganese is much like iron in its occurrence, its sources are more restricted; it is always present in igneous rocks but quantities are insufficient to allow residual deposits to form. However, residual deposits do develop from manganese derived from limestones, metamorphic silicate rocks containing manganese, and lodes distributed through bedrock. As with iron, tropical conditions are necessary for the formation of residual manganese deposits from silicate rocks. The formation of residual manganese deposits is accompanied by a great amount of solution and redeposition of manganese minerals. The main residual manganese deposits result from the weathering of crystalline schists in tropical and subtropical climates. As much less manganese than iron is present in limestone, weathering of limestone does not yield manganese ore unless the limestone was previously enriched.

Bauxite, a mixture of several hydrous aluminum oxides, is at present the only source of aluminum, and is therefore, after iron, the most important ore formed by residual weathering. It is derived from rocks high in aluminum silicates (clay, nepheline syenite, etc.) and low in iron, (otherwise an impure iron ore would have developed). Residual bauxite deposits are also formed from the solution of impure limestones. Tropical conditions, of course, are required to produce hydrous aluminum oxide; in temperate climates, clay is formed. As with all residual deposits, very special conditions must prevail in order for bauxite to form. The deposits are usually underlain by old erosion surfaces of low relief, which hinders runoff and allows downward seeping of groundwater. Good underground drainage to dispose of the waste products of leaching is necessary, as well as a long period of stable conditions and preservation from erosion, once the deposit is formed.

Deposits formed from nepheline syenite grade downward into unaltered rock; those formed from limestone lie upon an irregular layer of clay which overlies the limestone. Bauxite is always associated with clay. The age of most deposits is late Mesozoic or early Tertiary.

Clay, a hydrous aluminum silicate with varying amounts of impurities, although occasionally of sedimentary origin, as already noted, usually occurs in residual deposits. Most clay comes from the chemical decomposition of silicious crystalline rocks such as granite, whose feldspars yield kaolin (pure clay), potassium carbonate, and silica. If the last two are removed in solution, a very pure product results; pegmatites containing large feldspar crystals often weather to such a pure product. Basic igneous rocks, although containing aluminum silicate minerals, do not weather to high grade clay, as they contain too much iron, which stains clay derived from them. Clayey impurities in limestones often accumulate into residual deposits when rock is dissolved, but such clay, too, is often iron stained; these and other impure clays may be used for bricks. Clay is often washed to obtain a china-grade product.

Residual clay deposits usually assume the shape of the original rock; dikes of clay exist, as well as flat lying mantles grading into feldspar rich bedrock.

Because temperate, humid conditions are best for clay accumulation, glaciated regions, although they contain sedimentary clay, do not contain residual deposits.

Nickel is an important residual product of tropical weathering. Most deposits have formed by the weathering of shattered serpentine, which in turn was formed by hydrothermal alteration of underlying peridotite. Nickel is present in minute quantities in the peridotite, replacing part of the magnesium in the crystal lattice of the olivine. This nickel remains in the crystal lattice of the serpentine and is concentrated during weathering to laterite soil. The resulting nickel minerals are hydrous silicates, usually garnierite. Cobalt usually accompanies the nickel and is mined at some localities. At Nicaro, Cuba, nickel has been concentrated to about 1.4% in a blanket thirty to fifty feet thick.

Kyanite, used in refractories, is derived from kyanite-rich schist rocks, and occurs disseminated through clays.

Barite occurs in clay and is derived from the weathering of rocks and lodes.

Tripoli, fine silica derived from weathering of cherty or silicious limestones, and mineral paints (iron and manganese oxide and clay) are both residual products.

In Virginia and Tennessee, residual zinc occurs as the carbonate (smithsonite) and hydrous silicate (hemimorphite) nodules in clay.

In Netherlands Indies, cassiterite occurs in small residual placers. Residual cobalt is known in clay in Katanga.

Residual gold occurs in a few places in the world. In Alaska, conditions of weathering are unfavorable (cold climate, light precipitation, etc.), yet a few hillside deposits closely approaching residual concentrations are known. A relatively flat surface, and gold-bearing

bedrock or lodes are necessary for their formation. Many residual gold deposits have not been enriched by removal of worthless material, they owe their value simply to the fact that the enclosing rock is already broken down, and requires no milling.

Mechanical Concentration—Mechanical concentration produces mineral deposits known as placers, the name by which they will be referred to henceforth. One type of placer which is formed without transportation was just considered under residual deposits.

Placers, excluding residual placers, can be divided into (A) Stream placers, (B) Colluvial, or hillside placers, (C) Marine placers, and (D) Eolian, or wind-formed placers. Eolian placers, those in which worthless material is removed by wind, leaving the heavy metal, form only in arid climates; none exist in Alaska, so they will not be further discussed.

In Chapter 6, processes of erosion were described. In all of these processes, except glaciation, bedrock is broken down and removed by stream action, shore currents, or wind. Minerals of high specific gravity sink rapidly through the loose gravel and slide rock. If these heavy minerals are so durable that they cannot be broken down enough to be swept away, they may be held back by irregularities in bedrock, or sink below the depth to which movement of the loose material can take place, and form placer deposits. Some of the heavy minerals, as pyrite or cinnabar, may be brittle or soft or chemically unstable. Although these minerals may be found in placer concentrates, generally they do not travel far from their sources. The usual valuable minerals of placers are gold, silver, platinum, cassiterite, and gemstones — and to a lesser degree, and primarily in beach placers — magnetite, ilmenite, rutile and monazite. These last four are common non-economic associates of gold in placers even where they do not occur in commercial quantities.

Minerals of a placer do not necessarily come from lodes of commercial value. They may do so; (for example, the placers of Cleary Creek near Fairbanks were derived from lodes of Pedro Dome and surrounding country), but they may also come from low grade lodes, small stringers, or from the country rock itself (as does platinum), or from former placers. The discussion that follows is from the standpoint of gold, as gold is the most important placer mineral in Alaska, but the principles apply equally to other minerals.

Stream Placers form in the following way: in an area undergoing active erosion by the fluvial process, the entire surface is being lowered. All products of erosion are removed via the streams; rock debris and heavy minerals alike travel by mass movement from the ridges and hillsides into the creeks. The material in creek bottoms moves slowly downstream; otherwise the valley would fill up. Although some of the finer material near the surface of the stream bed is in almost continuous movement, the coarser gravel at depth moves only during high water. Every few years an exceptional flood occurs that moves all of the material to a depth on the order of five to fifteen feet, or even deeper. During such a flood the gravel near the surface moves several hundred yards, while that near the lower limit moves only an inch; however, from the standpoint of placer formation, the amount of downstream movement is not so important as the fact that the whole mass is agitated. During the agitation, of course, any gold in the stream bed works downward.

If the area is undergoing active erosion, as has been postulated, even bedrock in the stream bottoms is being eroded and lowered. The only way this process can take place is for the material in the stream bed, from the surface all the way to bedrock, to move occasionally during floods, and accomplish some abrasion. In an area undergoing vigorous downcutting, therefore, agitation of the stream bed material extends completely to bedrock, and the gold and other mineral concentrates accumulate there. Where the entire bed load is moving periodically downstream, any gold liberated from its bedrock sources in the catchment basin of a downcutting stream, eventually finds its way to bedrock in the bottom of the valley. Two factors besides specific gravity cause the gold on bedrock to move slower than the rest of the bed load. One is that the material near bedrock is moved only during times of very high water. The other is that the gold works down into any crack or irregularity (natural riffle) in the bedrock, and remains there until the riffle is worn away. If the stream is eroding an area that contains gold, the gold soon (geologically speaking) becomes distributed along the bottom of the valley trough in an elongated pattern called the *paystreak*.

A *paystreak* gradually fans out and becomes poorer downstream away from the source of gold, and a necessary requirement for a long *paystreak* is that an extensive mineralized area must be traversed by the stream. The existence of such a mineralized area can be determined to some extent if the small tributary gulches — "pups" — emptying into a stream carry gold; these are *feeders*.

The process described above continues so long as the regional base level is low enough so that the stream is downcutting. If the baselevel rises or if the stream lowers its valley to the point where it no longer is downcutting, the lower portions of the valley begin to fill in. Much of the material eroded from the head of the valley is deposited in the lower parts, but torrents still continue to move the upper portion of the valley fill downstream. This process causes agitation, intermittently, to a certain depth (perhaps five to fifteen feet); and if the base level remains stable for some time, a *paystreak* above bedrock develops. Sometimes the placer forms on an impervious layer such as clay; this layer is termed *false bedrock*. However, *false bedrock* is not neces-

sary for the formation of a paystreak above true bedrock. If the gold is available, the paystreak forms at the depth to which periodic agitation of the valley fill extends.

It is possible for a bedrock paystreak to develop even in a stream filling in its lower parts. So long as the stream is eroding headward, active downcutting occurs near the headwaters, and it is possible for a bedrock paystreak to develop in that area. As the stream continues to grow headward, the lower end of the zone of erosion becomes the upper end of the zone of deposition; the paystreak becomes covered deeply enough so that it cannot be further affected by agitation. Headward erosion causes an upstream migration of the boundary between the zone of erosion near the head of the creek and the zone of deposition farther downstream. The paystreak in this case is a trace of the upstream migration of the creek.

The heavy material accumulating with the gold is called concentrate. If the concentrate consists primarily of dark minerals (principally magnetite), the concentrate is called black sand; if primarily of garnets, it is called ruby sand. Usually the concentrate occurs in silt and clay tightly packed between rocks and boulders of the gravel. This material of the paystreak is called by some prospectors the "paystreak formation" or the "paystreak sediment". Differences in the composition and structure of bedrock in a creek often have a great effect on the amount of gold retained. Any irregularities in bedrock tend to catch the gold; smooth bedrock allows the gold to move on.

A placer being formed by the process just described is called a recent placer. A recent placer necessarily lies at a shallow depth, and is usually unfrozen. It is being formed during the present cycle of erosion.

When the base level of erosion is raised, streams become sluggish and choked with sediments; and any placers present become buried to more or less great depths. They are then termed buried placers. If the baselevel is then lowered and the rejuvenated stream begins eroding in a different part of its valley, a point may be reached where a "bench" apparently exists on the side of the valley. (A bench is an area in the valley of a stream, lying alongside the creek, and higher than the stream bed). In reality, bedrock under the "bench" may be as deep or deeper than that under the creek; the old placer is still a buried placer. A great many of the placers in Interior Alaska fall into this class.

Uplift of the region or lowering of the baselevel of erosion causes renewed cutting of the stream. By this time, the stream may be over on one side of the valley, away from the original paystreak; or it may be meandering back and forth, dissecting the paystreak and causing a new recent paystreak to be formed from portions of the old one. If the stream has migrated toward one side or the other when renewed erosion starts, the old paystreak may be stranded in its channel, high above the new one, forming a bench, or terrace placer; and if this process is repeated several times, successive placers may be left at different levels. Alluviation and rejuvenation, however, are not necessary for the formation of bench placers. Lateral migration during the downcutting in progress during the normal course of one cycle may produce the same effect.

By definition, bedrock under a bench placer is higher than that under the present creek; if it is as low or lower than that under the present creek, a buried placer exists. Both bench and buried placers are referred to as ancient; that is, they were formed during an earlier cycle of erosion.

If conditions are such that, when a stream begins to erode again after rejuvenation, an earlier placer is reworked by water and washed into the new channel, a richer placer is formed; and if this process is repeated, very rich deposits may result. It is sometimes found that the gravels of such reworked deposits are composed predominantly of quartz because the repeated concentration has weathered down and washed away many of the less durable rocks.

If the gold in a stream placer is relatively fine and the bedrock is uniform in composition and fairly well decomposed, the pay is spread uniformly along the paystreak; and small samples, such as are obtained from drill holes, provide an accurate idea of the value of the placer. Most of the stream placers of Alaska are of this type. However, if the gold is coarse, with few fines, and further, if bedrock is smooth, with occasional crevices in which the gold collects, the ground is very difficult to evaluate before mining. Such are the conditions in the Koyukuk district, in which miners have drifted on bedrock all winter until a small area was found which yielded the entire season's earnings. (Unfortunately there, as elsewhere, miners have drifted all winter without finding the small area which was to pay the grocery bill).

River bar placers comprise a special form of stream placer. They are formed of gold fine enough to be brought down by floods, much of it carried along in the current. True river bar placers are concentrations of this fine gold, dropped along with sand and gravel, in places where the water slackens. They are found usually on slip-off slopes of meandering streams. However, in Alaska, many of what are called "river bar placers" actually are bedrock concentrations. Usually these are formed where bedrock lies close to the surface of the river bottom. The rapids formed by bedrock provides natural riffles that trap the gold in pockets of gravel. Such placers are usually thin in comparison to their areal extent, and provide only small yardages. They may catch fine gold during flood stages, thereby becoming enriched.

Gravel Plain placers are those in which the gold is disseminated throughout a thickness

of gravel over a fairly wide area. They may form in the floodplains of a large river or on an alluvial fan. The agitation of gravel in innumerable small channels at different times during the construction of the fan results in a more or less uniform distribution of gold. Since gravel plain refers to a particular form rather than to a particular origin, it is conceivable that they might originate as marine placers. They are usually low grade and contain fine gold.

Colluvial, or hillside placers are formed on gently sloping surfaces where hillside creep and rivulets are slowly removing erosional products. They are not abundant, and are usually low grade; their chief economic value lies in what they contribute to later placers. A few have been mined during periods of favorable conditions. McCaskey Bar, in the Eureka district, is thought to be a hillside placer.

Marine Placers form on mineralized coasts. As described in Chapter 6, the action of waves on the shoreline abrades beach material until the lightest is swept away by undertow and longshore currents. Fresh material is continually supplied to the shore by streams and normal downhill creep along the shoreline. During stable periods in which the position of the shoreline remains fairly constant, any gold in the unconsolidated material of the coast or in mineralized bedrock undergoing marine abrasion becomes concentrated, and may form valuable placers. Such placers are long and narrow, parallel to the coast, and usually contain finer gold than do stream placers.

Placers formed as described above are called beach placers. Formerly it was thought that all placers along coasts were beach placers, but it is now realized that some bedrock paystreaks were formed offshore on the abrasion platform (see Chapter 6) by the reworking of beach placers inundated by rising sea level. Agitation of the unconsolidated cover extends to bedrock on the abrasion platform, allowing gold to settle rapidly and to lag behind as the sand is removed by longshore currents. For this reason, the term marine placer is used here to include both beach placers and abrasion platform placers.

If the shoreline is raised or lowered, the process starts all over in a new part of the shore profile; in this way several parallel placers may be formed, some on bedrock, some in the gravel overlying bedrock. A recent beach placer is one forming on the present beach, analogous to a recent stream placer. Presumably a recent abrasion platform placer can exist, but this

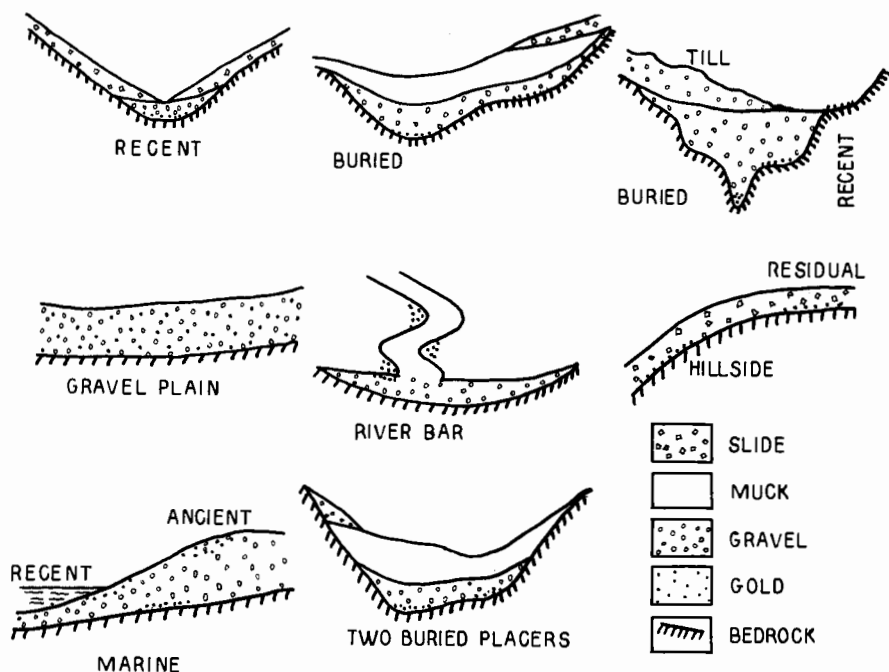


Fig. 7-4. - Cross Sections of Types of Placers. Type shown in upper right is sometimes found in glaciated areas.

is of little practical interest, since it must form offshore. Ancient beach or ancient abrasion platform placers were formed when the shore stood at some other position. Those inland from the present shore may be on bedrock or in gravel, above or below sea level. Ancient marine placers may also lie to seaward of the present shoreline, but this likewise is of little practical interest. An ancient marine placer lying beneath a thick cover is often called buried; one lying at an elevation below sea level is called submarine. These terms, however, are not satisfactory for classification.

Many of the rich placers of the Nome district are marine placers, and others exist in Alaska (on Kodiak and Middleton Islands, and at Yakutat), although not in sufficient concentration to form commercial placers. At Nome the placers are 200 to 300 feet wide and four to five miles long.

Some of the forms of placers described here are illustrated in Fig. 7-4.

Some confusion exists concerning the geologic age of Alaskan placers. The mineralization which produced the gold is thought to be of Mesozoic or Tertiary age (see metallogenetic epochs), and it is reasonable to believe that at least some gold began to be deposited in placers soon after it was formed in lodes. Yet most placers occur in stream gravels of Quaternary age. The gold has remained since its formation, but the early gravels have long since been broken down and eroded away; and the present gravel was formed in the Quaternary age. Only where the old gravels were protected do placers occur in Tertiary gravels. Alaskan examples of Tertiary placers are the cemented conglomerates of the Eagle-Circle district, the elevated "Nenana gravels" of the Bonfield and Kantishna districts, some of the "bars" of the Rampart district, and a buried stream placer in the Talkeetna district. Their chief economic interest is that they contribute gold to later placers.

In Chapter 6, under glaciation, a considerable amount of space was devoted to the possible effects of glaciation upon placer prospecting. It would be well for the reader to refer back to that discussion. Many classifications of placers consider those formed near glaciers to be separate and distinct from stream placers. In this book, however, they are considered as stream placers, formed by meltwater or reconcentration by recent streams of the gold in glacial material. Hence they have no distinct mode of origin. Perhaps the greatest fundamental difference between placers formed by normal stream erosion and by glacial stream erosion is that the reconcentration of gold in unconsolidated material plays a greater role in glacial stream action. This fact is illustrated by numerous examples in glaciated areas of rich placers occurring in narrow deep channels. These channels obviously only acted as sluice boxes through which tremendous volumes of gold bearing unconsolidated material were washed by meltwater.

OXIDATION AND SUPERGENE (SECONDARY) ENRICHMENT - The type of deposits included under oxidation and secondary enrichment, strictly speaking, are not separate and distinct,

but are parts of a preexisting primary lode deposit. However, because the process of oxidation and secondary enrichment, like the process of placer formation, has converted many uneconomic deposits into workable ores, it is considered as a distinct mode of formation of secondary mineral deposits.

When ore deposits, along with their enclosing rocks, are exposed to long continued weathering, the ore minerals above the water table are oxidized or dissolved by downward trickling solutions. The chief oxidizing or dissolving agent is water containing dissolved oxygen from the air. Oxidation of minerals by this agent yields other oxidizing solutions, among which ferric sulfate is the most effective. This oxidation of veins is very important where deep weathering has a chance to proceed; but there are many factors which work against the formation of an oxidized zone, especially in Alaska. Permafrost prevents oxidation, and extensive glaciation removed deposits formed by oxidation. Although deposits of oxidized ore to a depth of 3000 feet are known, the normal depths, where they occur at all, are from a few tens to a few hundreds of feet.

A picture of a vein oxidized under ideal conditions of weathering and mineral occurrence shows a rusty surface capping a few feet of iron oxides, called the gossan. Below the gossan is a relatively barren zone, from which the ores have been leached; below this, extending to

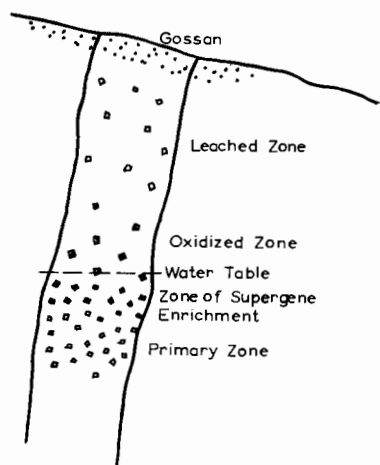


Fig. 7-5 - Idealized Zones of Oxidation and Secondary Sulfide Enrichment (after Bateman)

the water table, the zone of oxidized ores, in which the metals occur as oxides, carbonates, hydrous silicates, sulfates, chlorides, and native metals. Here, many minerals removed from the barren upper part may be concentrated. Below the water table, where oxidation ceases, the dissolved minerals from the oxidized zone are precipitated as secondary sulfides, sometimes forming very rich deposits. This zone of secondary sulfide enrichment grades downward into the original primary deposit, which may or may not be rich enough to mine for itself. Fig. 7-5 illustrates oxidation and secondary enrichment.

The gossan, or caprock, to the experienced geologist, implies many facts about the underlying deposit. It is always necessary, however, to bear in mind that the limonite of the gossan may have been formed by the oxidation of iron-bearing rock-forming or gangue minerals rather than from sulfides (ore minerals). Bateman gives a test for distinguishing the two: limonite of sulfide derivation is soluble in cold dilute hydrochloric acid; that from rock-forming or gangue minerals is not. Also, the prospector must remember that a gossan may cover a much greater area than the underlying mineral deposit (a mushroom gossan). The gossan may even have been formed by iron that has been transported a considerable distance and may not be connected to any mineral deposit (a false gossan). The remainder of this discussion deals with true gossans overlying mineral deposits.

The limonite of the gossan often displays a structure which it inherits from the predecessor mineral. It is usually cellular to the presence of voids left by the solution of sulfides. The cellular limonitic mass is called a boxwork. Another feature indicative of the original mineral is the color of the gossan (yellow, red, maroon, etc.) influenced by the oxidized compounds of elements other than iron which may also be present. The combination of structure and color may be quite diagnostic of the original minerals, but a description of the variation of gossan boxworks is not made here; for that detailed information, the reader is referred to any recent book on mineral deposits or mining geology. Inferences drawn concerning the kind and extent of mineralization simply on the basis of the structure and color of a gossan are dangerous, except when made by a specialist. The prospector who finds a gossan will spend his time to better advantage by digging into it to try to find remnants of the predecessor minerals or their oxidation products in place, rather than speculating from indirect evidence. Gossans should in all cases be investigated.

Even though ores occurring in the oxidized zone have provided some of the rich bonanzas of history, the oxidized zone of some deposits is barren. For extensive solution of the ore to occur, pyrite or other iron sulfide must be present to supply ferric sulfate and sulfuric acid, the principal solvents. The dissolved minerals are carried downward; they may continue to the water table, or they may be precipitated in the oxidized zone by any one of several conditions. The presence of carbonate (limestones for example) causes many metals, among them copper and zinc, to precipitate as carbonates as soon as they are dissolved. The ores at Kennecott, although subjected to oxidation for over 2000 feet, did not migrate nor form a zone of secondary enrichment, partly because they occurred in limestone and contained no pyrite to form ferric sulfate and partly because oxidation was interrupted by freezing during glaciation. Partial conversion to copper carbonates took place, however, to 2500 feet.

Carbon dioxide dissolved in the waters also causes the formation of carbonates. The presence of sodium chloride causes silver to be deposited as the chloride, cerargyrite. Lead becomes insoluble when acted upon by ferric sulfate and hence does not migrate downward.

Arid conditions are most favorable to a deep water table and, consequently, to deep oxidized zones. Another requirement for the development of an extensive oxidized zone is a slowly lowering water table, which in turn is dependent upon a slow rate of surface erosion. Too slow a rate of erosion results in a stationary water table, with stagnant water; oxidation soon stops because all the minerals down to the water table are converted to oxides. Too rapid erosion causes the oxidized zone to be destroyed as fast as it is created. This latter condition favors the formation of placers rather than oxidized zones.

The process may be interrupted in a number of ways: precipitation increases, drowning the oxidized zone and stops further oxidation; faulting plunges a block deep below the water level; or as happened at Kennecott, freezing stops all action. Conversely, a drop in the water table, caused by reduced precipitation or rapid canyon cutting, leaves the oxidized zone far above the water level; this however, can only be temporary.

Oxidation may be interrupted before oxidation is complete. Again citing Kennecott as an example, uplift, accompanied by rapid downcutting, left a zone thousands of feet thick above the permanent water table. Waters containing dissolved oxygen were carried deep into the deposits, resulting in the oxidation of about 25% of the copper ore before freezing stopped the process.

The prospector may have difficulty in determining whether a lode contains minerals of primary origin or of oxidation origin; but it is obvious that before development proceeds very far, he should seek geological aid to find out. If the deposit is found to be oxidized, it should be remembered that the ores will change in mineral composition and in quality; and probably that the ore extends to no great depth, unless the underlying hypogene deposit is rich enough to be worked. At any rate the mineralogy will change, and a different metallurgical treatment

will be necessary, increasing the cost of recovery.

Several minerals, among them native copper, gold, and silver, occur both in primary and secondary deposits. Certain minerals, however, definitely indicate oxidized ore. Carbonates, silicates and sulfates of copper and zinc, oxides of copper, antimony, cobalt, molybdenum and bismuth, silver chloride, lead sulfate, and lead carbonate are some such minerals. Specifically, the common minerals which originate only by oxidation are malachite, azurite, chrysocolla, cuprite, cerargyrite, smithsonite, hemimorphite, cerussite, anglesite, goethite, any iron sulfates, psilomelane, and garnierite.

Fortunately, many, (although not all) of the oxidation products of ore minerals are distinctively colored. The following list, after Bateman, gives the colors of minerals formed by oxidation that might be seen at the surface or in the oxidized zone.

<u>Mineral or Metal</u>	<u>Color of Oxidation Products</u>	<u>Oxidized Compounds</u>
Antimony	Pale yellow, white	Oxides
Arsenic	Green, orange, yellows	Scorodite, various oxides
Bismuth	Yellow	Bismite
Cadmium (in zinc)	Light yellow	Oxide
Cobalt	Black, brilliant pink	Oxides, "cobalt bloom" (erythrite)
Copper	Green, blues	Carbonates, silicates sulfates, oxides, native
Iron sulfides	Yellows, browns, maroons, reds	Goethite, hematite, limonite, sulfates
Lead	White gray, yellowish	Anglesite, cerussite
Manganese	Black	Oxides, wad
Molybdenite	Bright yellows	Wolframite, molybdenite
Nickel	Greens	"Nickel bloom," garnierite annabergite
Silver	Waxy greenish	Chlorides, native silver
Uranium	Black, green-orange, yellow	Phosphates, vanadates, etc.
Zinc	White, gray	Smithsonite

The zone of secondary or supergene sulfide enrichment is now considered. Metals not deposited in the oxidation zone finally reach the water table in solution and, in the absence of oxygen, replace sulfides and other metallic minerals of the primary deposit. To have supergene sulfide enrichment, several requirements are necessary. Weathering and oxidation must have taken place above the zone, and the primary ore deposit must be permeable to the descending solutions. The oxidized zone must be free of materials which cause dissolved minerals to precipitate there (principally carbonates). Pyrite must be present to furnish solvents (ferric sulfate is the chief solvent, and the metals are transported downward as sulfates). Minerals capable of undergoing secondary enrichment must be present (copper and silver are the most important). There must be a zone where there is no oxygen, usually the water table, and there must be metallic minerals below the water table to be replaced by the supergene minerals. If no primary metallic minerals exist to be replaced, secondary enrichment cannot take place. The process is usually one of replacement of the sulfide of one metal by the sulfide of a less soluble metal.

Sulfide enriched zones vary from a few feet to hundreds of feet in thickness, depending on the attitude of the original deposit and the other circumstances already mentioned as favorable to secondary enrichment. The zones also vary in degree of enrichment, depending again on the existence of favorable conditions.

Recognition of an enriched sulfide zone is important for the same reasons as is recognition

of the oxidized zone. If either zone is present, a gradational change downward is expected, probably into leaner ore. It is more difficult to recognize this zone than it is the oxidized zone. Although certain minerals are indicative of a supergene sulfide zone only one, sooty chalcocite, is absolutely diagnostic. The association of minerals is a helpful criterion, e.g., chalcocite and native copper; limonite overlain by malachite and cerargyrite. The zoning gives a hint; if, for instance, the tenor of copper sharply increases at a certain level, supergene enrichment has probably occurred. Texture of the ores seen under the microscope, in which one mineral is seen replacing another, is often diagnostic but beyond the reach of the ordinary prospector.

Copper, the most important metal of the zone of secondary sulfide enrichment, occurs mainly as chalcocite, covellite and native copper. Silver occurs as argentite, native silver, and several sulfo-salts. The rest of the useful metals are conspicuously lacking in the enriched zone. Zinc is thought to occur rarely as sphalerite and wurtzite (also a sulfide). Nickel, mercury, platinum, tin, cadmium, and gold (see next paragraph) may occur as rarities. Lead, bismuth, molybdenum, tungsten, vanadium or uranium are unknown in the zone of secondary sulfide enrichment.

As a rule oxidation and secondary enrichment have been unimportant in Alaska, except insofar as the oxidation minerals are brightly colored and, when seen on the surface, are a guide to underlying deposits. Even at Kennecott, where 25% of the copper ore was oxidized, no enrichment occurred, for the process simply converted chalcocite to carbonates, and no secondary enrichment occurred at the water table. Large parts of Alaska have undergone glaciation that destroyed the upper portions of the lodes, and the permanently frozen condition of much of Alaska during the Quaternary has inhibited oxidation. Oxidation and secondary enrichment are unimportant in Alaska for another reason: gold is the most widespread economic mineral. Some students believe that they detect a slight enrichment in gold at the water table in the veins at Fairbanks, but this is very difficult to prove. Theoretically, the gold was carried as a chloride, which was formed by reaction with free chlorine. Some slight enrichment of the oxidized portions of the veins is expected by leaching and removal of the sulfides enclosing the gold, and certainly this process would raise the percentage of free milling ore in the oxidized zone, a decided economic advantage.

METAMORPHISM (OTHER THAN CONTACT METAMORPHISM) - Metamorphic deposits differ from most other classes in that nothing is added during formation. All of the constituents of the mineral deposit are already in the rocks undergoing metamorphism; heat and pressure convert minerals already present to minerals more suitable to the new conditions. Metallic ores which undergo metamorphism do not change to new minerals but become streaked, banded, very fine grained, or otherwise changed in texture and are then called metamorphosed deposits. They are simply altered metallic mineral deposits. Metamorphic deposits, on the other hand, give us many nonmetallic minerals; the chief ones are asbestos, graphite, talc, soapstone, andalusite-sillimanite-kyanite, dumortierite, garnet and emery.

Asbestos is a general name used for several fibrous incombustible minerals, some of which can be woven into cloth; others are used for insulators (see Chapter 2). There are two main groups of these minerals, a serpentine and amphiboles. The serpentines are chrysotile, the most valuable, and picrolite. The amphibole asbestos minerals are amosite, crocidolite, tremolite, actinolite, and anthophyllite. Asbestos of both varieties occurs with serpentine and greenstone in the Kobuk area of Alaska.

Chrysotile occurs in serpentine altered from ultrabasic rocks or from magnesian limestones or dolomite. In ultrabasic rocks it occurs in three forms: in fibers perpendicular to the walls of the veinlets (cross fiber), in fibers parallel or oblique to the vein walls (slip fiber), and masses of unoriented fibers (mass fiber). In magnesian limestone, chrysotile occurs as cross fibers in serpentine bands between beds of limestone. The serpentine usually alternates with bands of unaltered limestone, and the chrysotile occurs "en echelon" within the serpentine.

Amphibole asbestos is inferior to chrysotile. The most important varieties are crocidolite and amosite, which occur as cross fibers in slates, schists, and banded ironstones in Transvaal and South Africa.

The origin of both types is obscure. It seems most likely, however, that chrysotile, which has the same composition as serpentine, was formed at the same time as serpentine, unknown differences in conditions causing one to be formed in preference to the other. Olivine can be converted to serpentine by the addition of water to form a hydrous silicate of magnesium, and chrysotile is serpentine whose molecules have been rearranged into fibrous form.

Of the amphibole asbestos, crocidolite is thought to be formed by the heat and pressure of overlying rocks, the materials being furnished by the ironstones from which they are derived. Amosite may be produced by contact metamorphism in part, as its composition is dissimilar from that of the rocks enclosing it.

Graphite occurs in two forms, as crystal flakes and as amorphous graphite dust. It is found chiefly in metamorphic rocks, but occurs also in igneous and sedimentary rocks. The modes of occurrence vary greatly. In metamorphic deposits, the graphite occurs as tiny flakes or specks disseminated through the rocks. Graphite may form by processes other than regional metamorphism, mainly as veins, dikes, and shear zone deposits. Graphite occurs at

Imuruk Basin on Seward Peninsula

The carbon of graphite comes from the enclosing rocks, but whether or not it is all of organic origin (as is clearly indicated where coal beds have been converted to graphite) or whether it comes from inorganic carbonates, is not known.

Talc, soapstone, and pyrophyllite have similar properties. Talc, the softest mineral known, is used for face powder, paints, and where a soft floky powder is needed. Soapstone is an impure talc rock used for smooth, soft surfaces such as switchboard panels. Pyrophyllite, a hydrous aluminum silicate, has similar uses.

Talc and soapstone occur in metamorphosed ultrabasic rocks or dolomite limestone. In limestone they are frequently associated with actinolite or tremolite. Pyrophyllite occurs in metamorphosed volcanics. Talc is an alteration product of magnesium minerals in the metamorphosed rocks, and pyrophyllite is similarly derived from aluminum minerals.

Andalusite, kyanite, sillimanite, and dumortierite are minerals which change to mullite, a refractory withstanding high temperatures. Together they comprise the sillimanite group. They all have slightly different modes of occurrence, but are all alteration products of aluminous minerals in metamorphosed rock and occur as disseminated crystals.

Garnets, which occur in schists and gneisses, are used for abrasives, as is emery, a mixture of corundum and magnetite.

CONTROLS OF MINERALIZATION

Bateman has listed the following broad classes of controls: structural controls, stratigraphic controls, physical and chemical controls, and controls by relationship to igneous intrusives, including zonal arrangements about such intrusives.

Structural Control

Control by structure is most important. Among the broad controls of this class are mountain chains, major faults, and areas of widespread igneous intrusions. It is an observed fact that most primary mineral deposits lie in mountainous regions. The mountains may have been worn down, but the roots are still there. Folds and faults, which act as avenues for ore fluids, are numerous in mountainous regions. Such regions also tend to contain thick sedimentary layers, in themselves reservoirs of minerals awaiting reconcentration into ore deposits. Also, igneous intrusions, the primary storehouses of mineral wealth, usually are abundant in mountainous regions.

Ore deposits are distributed along the lengths of very large faults in a few places in the world. These faults are believed to have been the channel ways for the movement of solutions which have supplied mineralization for an entire metallogenetic province. The controlling effect of small fractures, such as occur in single veins or mines, has been taken up in the discussion of hydrothermal processes.

Stratigraphic Controls

Stratigraphic controls, due to the presence of sedimentary layers, have as great an effect upon sedimentary mineral deposits as do structural controls upon primary deposits. The formation of geosynclines, which receive sediments for long periods of time, usually is followed by uplift and mountain building, with attendant igneous intrusion. These geosynclines, therefore, are associated with mountain building and with the ore deposits of mountainous areas. Besides this association with primary ore deposits, geosynclines may contain tremendous amounts of sedimentary rocks carrying relatively low percentages of useful minerals, which may be reconcentrated by leaching, if not rich enough to be mined as they are.

Basins of deposition, smaller than geosynclines, provide conditions identical to those found in geosynclines. Some of the products of sedimentary processes have already been listed.

Unconformities, old erosion surfaces, are favorable levels for the concentration of residual deposits such as bauxite, iron, manganese, and of buried placers. The weathered zone beneath the unconformity provides another form of channel way for the movement of mineralizing solutions. All types of stratigraphic controls are effective in concentrating oil and gas.

Smaller, detailed stratigraphic features such as bedding and, to some extent, schistosity control the migration of gas, oil, and water. Likewise, ore bearing solutions and gases are guided along bedding, which sometimes also provides the seat of deposition for ore minerals. Lenses of certain types of sedimentary rock, such as sandstone or limestone, often act as collectors of oil or water. Such lenses also may be replaced by minerals in solutions migrating along channel ways.

Impervious layers often provide barriers to migrating solutions which cause deposition. Impervious bases also sometimes act as dams for descending solutions, causing secondary enrichment deposits to form. The role of impervious layers known as false bedrock, in the for-

mation of placer deposits has been discussed.

Physical and Chemical Controls

Physical and chemical controls are not so evident, and the manner of their operation is less well understood than is that of the other controls; yet they are very important, especially in replacement deposits. Physical controls are those which depend upon characteristics of the rock such as brittleness, permeability, etc. There are innumerable examples of strong fissure veins becoming weaker or disappearing entirely when passing from brittle rock into tough pliable rock. The brittle, more competent rock shatters, forming channels for the solutions; the tough ones only fold. In others, permeability, as in sandstone, is sometimes the physical property which allows access of the ore bearing solutions.

Chemical controls are the least understood of all. Limestones especially have the chemical requirements to make ore, as has been seen when considering replacement and oxidation and secondary enrichment. At Kennecott, ore was deposited in dolomitic (magnesium-bearing) limestone, but not in pure limestone.

Although the preference for limestone and dolomite is the most pronounced, there are other preferences, almost impossible to explain. At Porcupine, Ontario, ore occurs in greenstones more than in quartz porphyry. At Noranda, Quebec, it favors rhyolite over andesite. One generalization frequently observed to hold is that the less silicic rock is the best host, although ultrabasic igneous rocks and highly aluminous rocks such as shale are not favorable. In rocks of intermediate composition, dark minerals are sometimes preferentially replaced by ore minerals.

The effect of chemical composition on ore deposition during oxidation and secondary sulfide enrichment has already been mentioned. Limestone causes carbonates of copper or zinc to precipitate immediately in the zone of oxidation. Non-calcareous rocks allow the leached minerals to reach the zone of secondary enrichment.

Control by Igneous Rocks

CONTROL OF POSITION - The very important role of igneous rocks in controlling the position of ore deposits on a broad scale is self evident; both the rocks and primary mineral deposits spring from a parent magma. The syngenetic mineral deposits are found within the igneous rock itself; pegmatite deposits are found in dikes or irregular intrusions around the igneous rocks. The sublimation deposits are found around volcanic vents. Contact metasomatic deposits lie at the contact of igneous rocks with the intruded country rock. Hydrothermal deposits are formed from actually within the outer zone of the intrusive to several thousand feet outside of it. Occurrences have been observed where dikes have graded into hydrothermal veins with increasing distance from the intrusive.

Examinations made over a long period of time and in many mines show that a relationship on a world-wide basis exists between type of hydrothermal deposit and distance from the intrusive. Structural, stratigraphic, physical and chemical controls affect the deposition, but other things being equal, a zonal arrangement with distance from the intrusive has been found. No one deposit shows the whole zonal sequence. One mine contains one portion, another mine another portion, and the entire sequence has been worked out from a study of many deposits. The property best associated with zoning is temperature; this fact leads to the conclusion that metals deposited close to the intrusive belong to the hypothermal zone; those farthest away belong to the epithermal zone; those in between belong to the mesothermal zone. The following is an ideal composite zonal arrangement from the surface down toward the intrusive: (After Bateman and Emmons)

Surface

- | | |
|--|---|
| 1. Upper barren zone | Low temperature gangue minerals; chalcedony, quartz, barite, fluorite |
| 2. Mercury | Cinnabar, commonly with chalcedony, marcasite, barite, fluorite veins |
| 3. Antimony | Stribnite, often passing downward into lead with antimonates |
| 4. Gold and Silver | Bonanza Tertiary ores of precious metals. Argentite, antimony and arsenic minerals common |
| 5. Barren zone | Most nearly consistent barren zone; represents bottoms of many Tertiary precious metal veins |
| 6. Silver | Argentite, silver bearing galena, complex sulfides. Usually silver decreases with depth. |
| 7. Lead (with some zinc, silver, copper and manganese) | Commonly carries silver, zinc (increasing with depth). Some chalcopryrite, gangue, quartz, and carbonates |

- | | |
|-----------------------------|--|
| 8. Zinc (and some lead) | Sphalerite with some chalcopyrite and galena; quartz gangue |
| 9. Copper | Tetrahedrite, often silver bearing. Merge downward into chalcopyrite, enargite |
| 10. Gold | With quartz, pyrite, arsenopyrite, chalcopyrite, grades downward into arsenopyrite |
| 11. Bismuth and molybdenum | Bismuthinite, native bismuth, molybdenite, quartz, and pyrite |
| 12. Tungsten | Tungsten minerals with quartz, pyrite, chalcopyrite, pyrrhotite, arsenopyrite common |
| 13. Tin | Cassiterite veins and lodes with quartz, tourmaline, topaz |
| 14. Barren zone with quartz | Gangue minerals |

Changes in type of mineralization are rapid and abrupt in the epithermal zone and so gradual as to be indistinguishable in the hypothermal zone. In the mesothermal zone there is gradual and perceptible change. This zonal arrangement occurs in primary deposits, and should not be confused with the zoning produced by oxidation and secondary sulfide enrichment.

As already stated, no such assemblage exists in one district; other controls can change or completely reverse this arrangement. Also, there are enough exceptions to the zonal arrangement to render it useless in predicting what lies at a lower level in a new prospect. Where the zonal arrangement has been established in a district, however, it may be helpful in prospecting.

The configuration of the boundary of the intrusive body tends to control the position of epithermal primary mineral deposits. The batholith has irregularities called cupolas protruding upward. Rising gases and fluids, carrying valuable metals, tend to concentrate in these cupolas, which are, therefore, the localizers of mineral deposits. Four features near the upper surfaces of batholiths are recognized and named (Emmons):

1. The roof, composed of the invaded rocks;
2. The hood, or upper part of a batholith;
3. The core of the batholith, generally barren of minerals;
4. The dead line, an imaginary upper surface within the batholith, below which economic deposits rarely form.

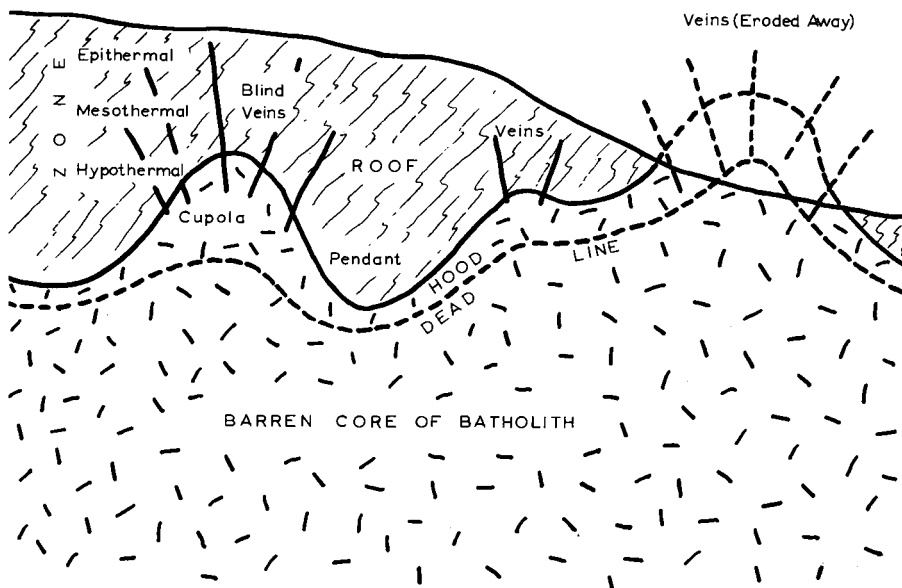


Fig. 7-6 - Idealized Relationship of Mineral Deposits to Batholith (After Emmons).

Roof pendants are those portions of the roof which extend down between the cupolas. They are favorable zones for the localization of veins filling fractures that frequently extend out from the cupolas. Cupolas may be circular or elliptical. Circular cupolas are rare, but where they do occur, the fractures are in a radial pattern around them. Fractures around elliptical cupolas are oriented parallel to the long axis of the ellipses, and may be filled to form parallel systems of veins. All these features are illustrated in Fig. 7-6.

Certain observed occurrences are explained by the foregoing concept of cupolas, roof pendants, and dead line. It is known that lodes tend to be distributed around small stocks rather than batholiths. (A stock represents a cupola that has been intersected by the surface of erosion). Erosion that has preceded this far will bare the upper parts of the batholith and adjacent roof areas where mineral deposits are expected to form. If erosion has proceeded further, baring the main body of the batholith over a large area, the barren core where no deposits were formed is exposed. Deposits exposed by an erosional surface several hundreds or thousands of feet above a cupola are more likely to be epithermal, but those close to a cupola are likely to be mesothermal or hypothermal.

CONTROL BY TYPE OF ASSOCIATED IGNEOUS ROCK - In the discussion of primary deposits of magmatic concentration origin, the relationship between certain types of rocks and the enclosed ore deposits was pointed out. Basic and ultrabasic rocks are the chief representatives; and as the deposits actually lie within the rock, the relationships cannot be mistaken. A rather close correlation is found.

Primary epigenetic deposits also show a correlation between ore minerals and type of rock, but not so close as the magmatic concentration deposits. Epigenetic deposits usually are associated with less basic rocks than are magmatic concentration deposits.

Even among the epigenetic deposits, however, the generalization can be made that the relationship shows a closer correlation among the basic rocks than among the more acidic rocks.

No attempt is made to associate mineral deposits with extrusive rocks, and no association is observed. Both mineral deposit and lava are assumed to have originated from the same magma reservoir at depth. The following associations between intrusive igneous rocks and ore deposits have been observed. *

<u>Intrusive Igneous Rock</u>	<u>Associated Ore Metal</u>	<u>Chief Mode of Origin</u>
Kimberlite-Eclogite	Diamonds, Garnets	Magmatic concentration
Peridotite-pyroxenite	Chromite, Platinum Chrysotile asbestos	Magmatic concentration Metamorphism
Norite	Nickel-copper sulfides	Hydrothermal, possible magmatic concentrations
Gabbro-Anorthosite	Titaniferous magnetite	Magmatic concentration Contact metasomatism
	Ilmenite	Magmatic concentration Hydrothermal
	Native Copper	Hydrothermal
Dolerite-diabase	Silver-Cobalt-Nickel	Hydrothermal
Diorite-Monzonite	Magnetite	Magmatic concentration Contact metasomatism
	Copper	Contact metasomatism Hydrothermal
	Gold	Contact metasomatism Hydrothermal
Granodiorite-quartz	"Porphyry" coppers	Hydrothermal Contact metasomatism

* - After Bateman

<u>Intrusive Igneous Rock</u>	<u>Associated Ore Metal</u>	<u>Chief Mode of Origin</u>
Monzonite-quartz diorite	Base metals	Hydrothermal Contact metasomatism
	Gold-silver	Hydrothermal Contact metasomatism
	Molybdenum	Hydrothermal Contact metasomatism
	Tin-Tungsten	Hydrothermal Contact metasomatism
Syenite	Magnetite	Magmatic concentration
	Gold	Hydrothermal
Nepheline Syenite	Corundum	Magmatic concentration Contact metasomatism
Granite and Granite pegmatite	Tin	Hydrothermal
	Tungsten	Hydrothermal
	Uranium	Hydrothermal

References

- Bateman, Allan M., 1950, *Economic Mineral Deposits*: John Wiley and Sons, New York
 Emmons, W. H., 1937, *Gold Deposits of the World*: McGraw-Hill Book Co., New York
 Hopkins, D. M., 1956, *Unpublished Notes on Placers*
 Lindgren, Waldemar, 1933, *Mineral Deposits*: McGraw-Hill Book Co., New York
 McKinstry, Hugh E., 1948, *Mining Geology*: Prentice-Hall, Inc., New York
 Mertie, J. B., 1923, *Geology and Gold Placers of the Chandalar District, Alaska*: U. S. Geological Survey Bull. 773
 1939, *Platinum Deposits of Alaska*: U. S. Geological Survey Bull. 910 b
 Spencer, W. W., 1948, *The Platinum Deposits of Goodnews Bay, Alaska*: Thesis, University of Alaska



PART TWO
PROSPECTING



Chapter 8

BACKGROUND

Before starting the study of applied prospecting, the beginner should be aware of some general facts concerning prospecting in Alaska. First, however, the person who would be a prospector should read the next paragraph. If he does not like what he sees there, he need read no further.

The odds against finding a deposit are great, and those against making any money from this deposit are even greater. These obstacles the prospector should realize and prepare himself to face to the best of his ability, both in knowledge and in equipment; for it is only through these tools that he may reduce the odds against him. In fact, even after he so prepares himself, the odds will still be so great, that the prospector should plan at the outset to have some other means of support and should look on his prospecting as a part time occupation in which he is investing time and money in a possible future mine.

FINANCING PROSPECTING

Many early day prospectors were able to practically "live off the country." Jobs were scarce but living was cheap, because many necessities came from the land. Some money had to be brought in, and often this, too, could be earned from the land. Money was worth more then than now, and the prospector made a greater effort to get it, often working for a few dollars a day "sniping" shallow placer ground in a known area to finance his prospecting in other areas. Cutting steamboat wood in the winter along the rivers was another source of income as was part time trapping. Finally, there was often the opportunity of working for wages in some hardrock mine or placer drift mine during the winter to finance the next summer's work.

These methods of financing prospecting have become increasingly difficult for a number of reasons. The pockets of high grade ground that can be "sniped" are almost impossible to find, and the returns for working them are insufficient to meet today's high costs. The steamboats have been replaced by diesel tugs, and winter mining has all but ceased.

Other ways are open to the prospector, however. He may work for a year and prospect for a year, an arrangement which leaves him independent of others. He may enter into a "grubstake agreement" with another who contributes the outfit and transportation while the prospector contributes his time and knowledge. Since the money value of labor has increased so greatly, the matching of outfit against labor is no longer equitable, and some wages must be paid to equalize the contributions. Such equalization may be handled easier by a group, some of whom contribute money, some labor. In this way, equipment can be procured which increases greatly the chance of finding a deposit, and it allows the work to be carried on long enough to prove or disprove a prospect. One small drill, drawn by a tractor, increases the placer prospector's productivity tenfold, and if the tractor is equipped with a blade for stripping overburden, surface prospecting on lodes progresses at more than ten times the rate of handwork. Sometimes the grubstake is a mining company which pays a prospector a low wage, plus expenses. The prospector gets a share in the ownership of whatever he finds, and the company gets the exclusive right to develop the property, unless it is decided to sell to another company.

The ideal arrangement for the prospector, of course, is to be able to finance his work from royalties or payments from previous discoveries.

Certain government aids that are described in the appendix are available for the prospector.

THE PROSPECTOR

The term "prospector" is applied to many types of men. Perhaps in no other field is there so great a difference in ability as among those who call themselves prospectors. The reason for this difference is that prospecting is a field that lends itself to part time occupation and is looked upon by many as part sport, part work. Some men work for wages only long enough to obtain money to return to their prospecting; others prospect only for short intervals between jobs. The difference in their experience soon shows up in the skill which they develop.

Perhaps the best prospectors make their living as miners. They are thoroughly familiar with mines and minerals and understand what they are searching for. Most mining techniques somewhere find application in prospecting, so these mining men have a good basic knowledge with which to start. The only man who masters the techniques of prospecting better than the part miner-part prospector is the full time prospector who works for a mining company or who has an

independent income and can afford to devote all his time to prospecting. The man with mining experience has one advantage over the man exclusively a prospector - he knows what constitutes commercial ore and is not so likely to waste time on worthless projects.

A good prospector likes his work; for him it is the most interesting work in the world. He is optimistic, for although he knows the odds are against his finding a mine, he has confidence in his ability (by study and application), to reduce the odds to the point where the chance for reward is worth the risk. He has long since mastered the techniques of getting along in the country but is anxious to learn more.

He must train himself to disregard comfort. This can be done very easily. He will, at the outset of his career as a prospector, be thoroughly miserable a few times, so that his normal state seems easy by comparison. Perhaps the best training for the prospector in this regard is to pack on his back for several days some non-essential item. He will soon decide that any possible comfort derived from that particular article is not worth the discomfort of packing it.

Finally, a good prospector never loses sight of the fact that the purpose of prospecting is to find a mine. He never allows prospecting to become an end in itself.

Each time and place develops its own type of prospector. In the western United States one type is developed, in Canada and southeastern Alaska another, and in Interior Alaska, a third. Most of Canada and southeastern Alaska were covered during late Pleistocene time by a continental ice sheet, which provided good outcrops over much of the land and has tended to develop a class of hardrock prospectors. Even when drift covers the country as it does in much of Canada, mining and prospecting are directed principally toward hardrock deposits because any placers that might have existed were scattered by the ice.

In Interior Alaska and the adjacent unglaciated parts of Canada, bedrock exposures are obscured by a mantle of windblown material and other overburden. Here a class of prospectors developed who were primarily interested in placer prospecting, although men with hardrock experience have continued to look for lodes.

Other factors, such as transportation costs, also influence the type of prospecting that is carried on.

AN ANALYSIS OF THE PRESENT STATUS OF MINING AND PROSPECTING IN ALASKA

In many parts of the western United States, placer mining opened the country, lode mining of gold and base metals soon followed, cattle ranching, logging, and farming were established, and there was a steady trend toward industrialization.

Alaska, isolated as it is by thousands of miles from population centers which alone can supply the market for any substantial production, has not followed this path. Only southeastern and other southern coastal areas enjoy cheap transportation, and it is significant that gold and copper lode mining, fishing, and logging developed there. The growth of population in the West, and the northward expansion of western populations will, of course, eventually increase the demand for Alaskan commodities.

Lode gold mining was ended by the Second World War and postwar inflation, and known copper reserves have been worked out. It cannot be expected that large scale, low grade lode gold mining will revive in the near future. What about base metals? The same conditions that favored the development of lode gold mining in southeastern Alaska also favor lode base metal mining, and there is considerable interest in this area. Metals that can be located with airborne geophysical devices especially are being found. With these devices (airborne magnetometer and airborne scintillometer) many of the natural obstacles that make surface prospecting in southeastern Alaska very difficult are overcome. Thus, uranium and iron from magnetite are two commodities that show promise in southeastern Alaska. Economic conditions there are enough like those in other states so that fairly low cost items can be mined and exported profitably. This basic fact is recognized, and today large companies are more interested in the mineral possibilities of regions south of the Alaska Range than in those north of the Range. Any realistic appraisal of the future development of Alaska mining and of the prospector's part in it must be based upon this realization. From an economic standpoint, it is a far better investment for the prospector to spend his time searching for base metals south of the Range rather than to the north.

North of the Alaska Range, high transportation costs which must be paid on mining materials imported and on concentrates exported, added to the already high labor costs, make base metal mining hazardous. The only large scale base metal mine in the Interior, the Kennicott Copper Mine, was very rich, as it had to be to allow the company to build and maintain 195 miles of railroad through rugged country.

There is being developed at the present time, a large copper deposit just north of the Kobuk River. This deposit undoubtedly will become a large producer and an important factor in the future mining economy of Alaska. How soon it can come into production depends upon market and upon what transportation costs can be arranged. A favorable item is the fact that lighters can be brought up the Kobuk River, avoiding expensive trans-shipment. Water transportation -

even on an Interior River - will greatly enhance its economic situation.

Another large operation that may develop in the Interior is oil production. Oil, however, once it has been located by wells, requires little labor to produce.

In the Interior, Anchorage and Fairbanks and the areas along the roads have absorbed most of the people formerly distributed throughout the country. Only expansion of the mining industry can stop this trend in the near future. For this expansion to take place, new deposits must be found, and the prospector, either working for himself or for a company, must find them.

Even so, it cannot be expected that the country will be populated to its former extent. Thirty years ago a small placer mining camp of three or four creeks might support a hundred miners, plus a dozen freighters and several tradesmen and professional men. Most of the money produced went directly to these people. Today the airplane has by-passed the tradesmen and professional men, to a large degree, bringing supplies and services from distant trading centers. A very large proportion of the money now received from each cleanup also leaves the community to buy fuel oil and mechanical equipment elsewhere. The some mining camp of three or four creeks today might have a population of thirty or forty people during the summer and not one during the winter, for the airplane takes the people to more hospitable surroundings in the fall, leaving no one to prospect.

The foregoing discussion of mining and prospecting presents a gloomy picture, but actually the "gloomy picture" consists of a recitation of changed conditions. The task confronting the realistic prospector is to see under what conditions prospecting can be conducted to meet the changed conditions and to aid in this analysis, some of these conditions are listed and discussed.

1. As the richest and easiest found deposits are exhausted, the odds are becoming greater against the prospector finding a mine. But most of the discoveries in Alaska were made between 1898 and 1915 when thousands of men were roaming the country, and even then, some lay undiscovered in their midst for years. While it is unlikely that any new large camps will be discovered by a prospector stumbling onto an outcrop, new creeks and new lodes will certainly be found. Improved knowledge of geology and prospecting techniques must be applied to increase the chances of discovery. It might again be noted that the large copper deposit near Shungnak was not developed until the 1950's and 60's.

2. Because of improved standards of living, modern man is unused to hardships. Here a compromise must be struck by decreasing the standard of living somewhat, at the same time taking advantage of modern conveniences that are practical for living in isolated places.

3. The airplane transports people to and from Alaskan points without giving them a chance to examine the country. This disadvantage is offset by the additional time available for prospecting which formerly was consumed in travel, and the prospector should use quick transportation to get him and his supplies to the section in which he is interested.

4. Many overland and water routes have been abandoned due to air travel, actually increasing transportation costs to some areas. This factor is rapidly becoming less important as improved planes and competition decrease the cost of air travel. Time saved obviates the necessity of tying up money in outfits, sometimes a year in advance, and partially offset the increased cost.

5. Inflation has decreased the buying power of gold and increased the cost of mining it. This condition can be overcome by increased efficiency through use of new methods and equipment. The prospector may also turn to base metals, the price of some of which has kept pace with other costs.

6. Government construction gives employment at higher wages than the mining industry can pay, depressing mining and prospecting, especially for gold. The prospector and miner can overcome this only by doing a greater proportion of the work himself with the help of labor saving devices. Already this factor has resulted in the development of labor saving devices in placer gold mining.

7. A lower percentage of the production of mines goes to pay wages; therefore there is less chance for the prospector to make his grubstake working in the mines. The lack of drift mines and lode mines also makes it difficult to find winter work in mining. This problem is serious, as it makes it necessary for the prospector to earn his grubstake far from his prospecting area and does not allow him to become as familiar with the country as he might otherwise. The only solution is for the prospector to leave the district when he needs work and to work for longer periods of time to offset the added cost of transportation to and from the prospecting area.

8. Sixty years of history makes men less optimistic about making a fortune. This factor is one for which there is no remedy. The prospector must be tough minded and realistic about his chances; and if he doubts his ability to train and equip himself sufficiently to overcome the odds against him, he should not prospect. There is no virtue in blind optimism.

9. Through disuse, some of the arts of prospecting under conditions peculiar to the north are being lost. New techniques, however, are also being developed, and geological research is improving knowledge of permafrost and arctic countries in general.

10. Prospecting expenses are only partially deductible from taxable income. If all prospecting expenses were deductible, a greater effort would be made, but this deduction can only be accomplished by federal legislation.

11. Capital is becoming increasingly disinterested in Alaskan gold prospects. This fact is another one which must be faced, and it is up to the prospector to demonstrate that his prospect can be made into a mine. There is the possibility that some legislative relief may be forthcoming, adding increased incentive to gold prospecting.

The evaluation of the "old timers" and their work is another subject which must be explored. Most of their work was done during the first fifteen years of this century, and at that time the majority of the men were not what we would call "old timers"; in fact, many of them were totally inexperienced, as they will today admit. However, thousands of them moved over the country looking for float and panning the creeks, but this period of intense activity lasted only a few years. A close look also indicates that many of the thousands who stampeded to new camps never did any prospecting. The most intensive work was done right around the producing camps, leaving vast areas in between which contained creeks that have never been panned and ridges that have never been walked. Granted that the old timers were industrious and persistent, but there simply was not enough time for them, using the methods at their disposal, to prospect the country thoroughly. In placer prospecting, a creek cannot be said to be prospected until it has been "crosscut from rim to rim", or until it has yielded samples from bedrock at sufficiently close intervals across the creek so that there is no chance of missing the paystreak. One shaft does not indicate that a creek has been prospected. Where the ground is thawed and wet it is likely to be unprospected, for without drills or pumps, the old time prospectors could not reach bedrock.

On the other hand, it is common belief that the oldtimers overlooked a great deal which we today will recognize. It is said they recognized only gold, and were not interested in anything else. This statement, of course, is pure wishful thinking. Geologists of the United States Geological Survey visited all the creeks and most lode prospects as they were discovered, and helped the prospectors to identify other minerals. Possibly some mineral in minute amounts, or one which has acquired value since then, may have been overlooked or disregarded but it is difficult to think of one occurring in quantity which was overlooked completely. Some minerals simply were not sought, such as uranium, which in 1955 was discovered within a few miles of the coast on Prince of Wales Island in Southeastern Alaska. At Eva Creek, in the Bonfield District, however, the prospectors were well aware that their concentrates contained bismuth, and they made a search for the source, discovering it in a gold bearing lode.

Another belief is that the old timers left behind as much gold as they took out. This is true for those deposits in which the limits grade out gradually on the sides of the paystreak and where much of the gold occurs in the gravel some distance above bedrock, especially if the ground was originally drift mined. Where the gold is concentrated on bedrock in a sharply confined paystreak, however, most of the gold was removed. For this reason it is a dangerous oversimplification to say that the old timers left as much as they removed.

BRIEF HISTORY

A brief outline of the history of Alaskan mining and the role of the prospector in Alaska provides an insight into the present status of prospecting in Alaska. Before the United States purchased Alaska, prospecting seems to have been confined to one company-financed experiment on Kenai Peninsula which failed. Before the 1870's, 80's and 90's, several camps were discovered in southeastern Alaska. Placer mining attracted the first prospectors, and a few discoveries were made. Lodes, however, provided the principal and most lasting deposits. In 1880, the deposits at the present site of Juneau, both placer and lode, were found; and hardrock prospecting up and down the coast and on the islands by men experienced and more or less familiar with mining was accelerated.

The Mines on Douglas Island, collectively known as the Treadwell, which operated from the 1880's until they were flooded by the sea in 1917, provided the experience and grubstakes for men who occasionally penetrated the Interior farther north. These men who went to the Yukon were true pioneers. Some of them made their living by trading, or trapping and selling their skins to traders, but many of them outfitted themselves with enough provisions to carry them through several years of prospecting. During the 1880's and 90's, they discovered the Stewart River of Yukon Territory, the Forty mile, the Rampart, and the Birch Creek (Circle) camps.

Two ships arriving at Seattle from the North about the middle of July, 1897, carried miners possessing a total of well over \$1,000,000 in placer gold from the Klondike. This precipitated the Klondike Stampede, which in turn set off the movement that carried men to every corner of Alaska in the next one and a half decades. Thousands converged on the Klondike; and Dawson sprang up overnight. Among the stampedeers were people from all walks of life, and as among all stampedeers, many came who had no idea of how to go about prospecting or mining. Many turned back, and others must have felt confused and dazed when they finally reached the "promised land". However, many men were experienced and competent and set about discovering and learning new techniques to enable them to cope with new conditions found in the North.

A mining camp is a pin point on the map, and the number of producing creeks or lodes in each one can be counted on the fingers of a man's hands. By the time a stampede would be

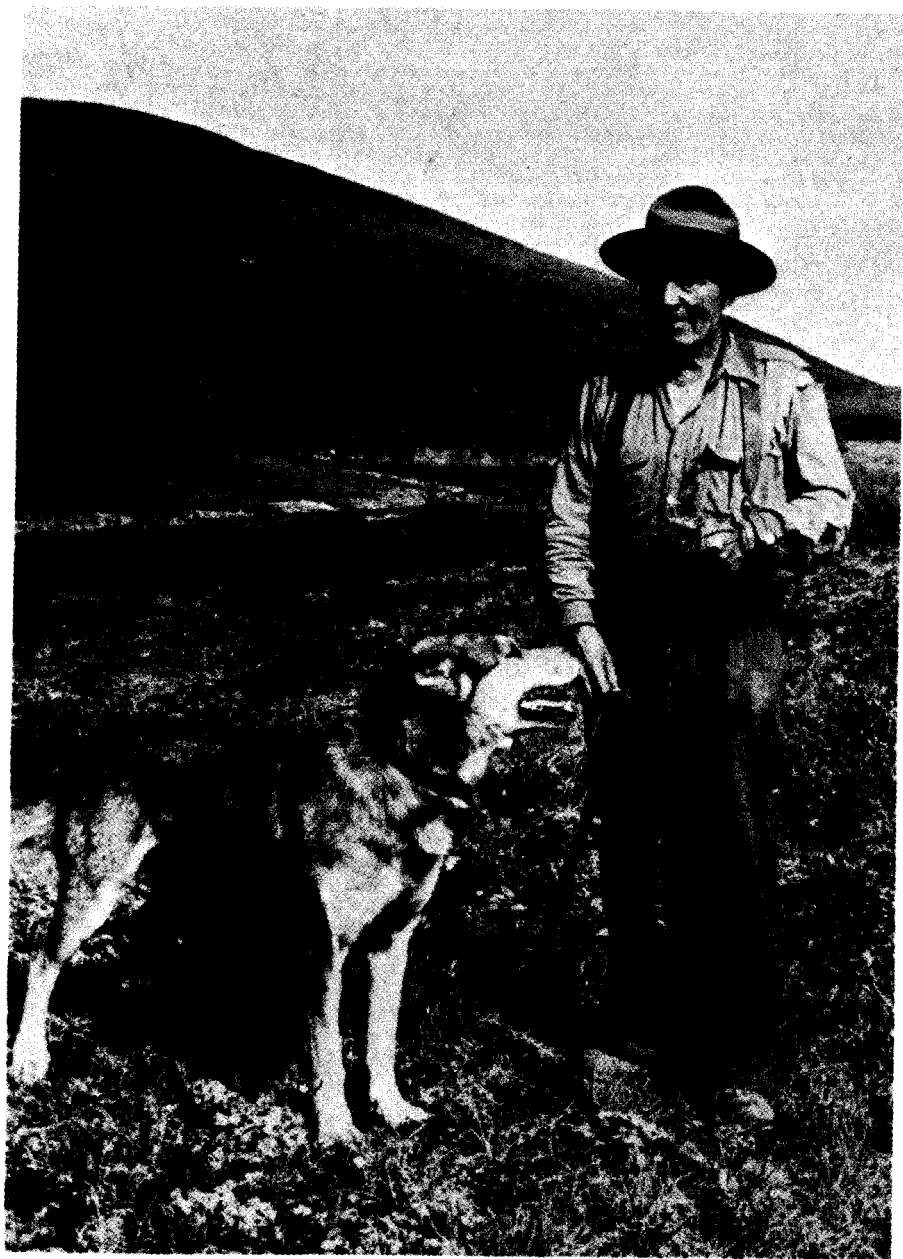


Fig. 8-1. - Sixty Years of Prospecting. A Veteran of the Kobuk Stampede Still Looks Forward to a Big Strike.

under way, most of the good ground would be staked, and the camp would have a surplus of thousands who could not even find work to support themselves. The more enterprising of these spread out and prospected in other parts of the North. Some men, of course, foresaw what conditions would be in Dawson and took ship directly to other points; among these also were many who were just stampeding.

In this latter class were 2000 men who landed at Kotzebue Sound in 1898 in what is known as the "Kobuk Stampede." The story of this stampede is little known, and it made little impression on the economy of Alaska, but the following experiences of a small group of the participants throws light upon the prospector of the Interior during the period:

"We thought that all we had to do was to get to Alaska, and that gold was everywhere," one of the participants has said.

This quotation sums up the popular attitude at the time. When they landed, some of the men set off up the river immediately, in order to be the first to the largely non-existent gold fields. By the first winter men had spread out upon the Selawik, the Kobuk, and the Noatak, where they wintered as best they could, many dying of scurvy. It is of interest and carries an instructive lesson, that in spite of the number of men active, the Squirrel River placers were not found until 1909, many years after the stampede and the large copper deposit near Shungnak, although suspected early in the century, was not proved until 1963.

The stampedeers of 1898 were ready to rush anywhere a rumor said that gold might be found, but by spring most of them were destitute and some had to be transported out by the Revenue Service. A few of the men who left reached Nome in time to take part in that stampede. Of the 2000 who came to the Kobuk district in 1898, only a handful remained the next year, and these began the exploration of the country and at the same time began acquiring the skill and experience at prospecting which was to be their stock in trade. They worked up the Kobuk in poling boats, panning the streams as they went. One group wintered at the Reed River Hot Springs in 1899-1900, pitching a tent right over the spring.

In 1898, Lucky Six Creek, at the head of the Noatak, was found, but after hauling boxes built of whipsawed lumber 30 miles from timber, the next year's returns did not justify further work. The group portaged to the Alatna and descended to the Koyukuk on rafts, one of which turned over, causing much discomfort and hardship.

Most of these men went up the Koyukuk River to Coldfoot, the settlement serving the newly discovered Upper Koyukuk Camp. Some of them worked north and east from there, discovering Jim Pup at Big Lake, thirty miles above the present site of Wiseman. In 1900-1901, they wintered on Bettles River, north of Big Lake, and for the next few years mined and prospected with indifferent success in the Koyukuk district. One of them made a trip back to the Alatna to investigate a prospect found there during the trip over from the Noatak in 1900.

When the Chandalar district was struck in 1906, they stampeded there. Some made a little money mining or working for miners, and roamed the Chandalar and Koyukuk districts, prospecting and mining, always looking for gold.

This sort of effort was being made all over Alaska. After Pedro found gold in what was to become the Fairbanks camp in 1902, thousands stampeded there. Only those who had been in Dawson or some other active camp had acquired sufficient experience to prospect intelligently; and it was 1904 before much activity began.

By now men thought they could see the odds at stake. If Felix Pedro could go into a new country and discover a mining district, as well as found a new city and give his name to several prominent geographical features, anyone might become an empire builder in a few short years of work. If Dawson, Nome and Fairbanks had sprung into cities overnight, with railroads, telephones, steam power plants, and telegraphic connection with the Outside, (continental United States - "outside the Territory of Alaska") why should not there be a hundred potential cities awaiting some lucky chance to bring them to life? There was nothing incongruous about a prospector in rags, a hundred miles from the nearest settlement and sixty miles north of the Arctic, almost out of supplies, who thought the most important business at hand was the measuring of a certain rapids to ascertain whether or not enough hydroelectric power could be generated to meet the industrial needs of the community which might be about to spring up.

These men did find new camps, although none were so extensive as the discoveries at Dawson, Fairbanks, or Nome. In quick succession were found the Tenderfoot, Bonfield, and Kantishna gold districts; the copper of Prince William Sound and Kennicott; the Iditarod, Innoko, Chisana (called by them the Shushana), Tolovana (Livengood), and other districts. This period lasted until the First World War; new camps were being found all the time, and work was to be had in those already discovered whereby the prospector could get a grubstake. Optimism was also shared by those having investment capital, and it was relatively easy to interest companies in new mines.

When they came to Alaska, these men were inexperienced "green hands." Many rapidly became good prospectors, but many of the discoveries were made by sheer weight of numbers. So many men were prospecting that some with any diligence had to find mines. Placer prospecting, in general, followed the initial discovery of a camp and combined the steps of prospecting, looking for a mineral deposit, with exploration, determining its limits. From this

period dates the saying that "there has been a hole put down on every creek in Alaska," which in not strictly true, and even if true would not rule out further discoveries.

Even in well known camps, creeks lay undiscovered for years, while men were prospecting all around them. A few examples, which could be multiplied many times, will suffice. The Squirrel River placers, which were not found until 11 years after the Kobuk Stampede, have already been mentioned. The deep channels on Nolan and on Hammond creeks in the Koyukuk district were discovered in 1907 and 1911 respectively, after several years of activity. The richest ground on Little Squaw Creek, in the Chandalar district, was discovered over ten years after the creek was first located.

The end of the first era in Alaskan prospecting was approaching. By the time the United States entered the First World War, the richest of the placers were worked out; and many of the young and single men who made up the body of prospectors went into the army or were attracted Outside by high wages. As the drift mines were worked out, it was assumed that the Interior Alaskan camps would follow the pattern established in the mining districts of the Western United States and Southeastern Alaska, where placer mining sufficed to open up the country after which lode mining began, followed by the establishment of other industries and agriculture. About 1912 several lodes were opened up around Fairbanks, but the lives of most of them were short. Small isolated lode gold mines were successful in the Interior, however.

During the First World War and the early 20's, activity in the Interior was greatly reduced, although copper and gold lode mining south of the Alaska Range prospered. Gold mining and prospecting flourish during depressed times and are depressed during prosperous times; hence the time was unfavorable for gold. The rich placers which could be mined by drift methods were becoming exhausted; and about the only efficient method of open cut placer mining at the time was dredging, which required a large investment and a fairly large deposit. Worse, as no significant discovery of placer gold had been made since 1914, it was beginning to be suspected that fortunes perhaps were a little hard to find. Still, costs were not too high; a living could be made mining, and many prospectors took to the hills each year.

The building of the Alaska Railroad made possible large scale dredging of what was left in the Fairbanks camp and had a rejuvenating effect upon the whole Interior mining industry. This advance in transportation, coupled with an increase in the price of gold ten years later during a period of depression in other industries, caused a boom in gold mining during the thirties. By this time, mechanical equipment had improved to the point where bulldozers and draglines played a major role in mining methods.

Steam driven drills had been in use for many years, especially for prospecting and drilling ground. During the 20's and 30's, drills came into fuller use and small gasoline driven "air-plane drills," sufficiently powerful to drill shallow ground, were put on the market. Still, no great number of men entered prospecting, although many miners carried on exploration of different parts of the creeks on which they were working and gradually discovered a few more creeks. The discovery of such new deposits lagged behind the exploitation of the old ones, however, and the increase in production was due to development of better methods of moving dirt and to the higher price of gold. New reserves also were discovered by dredging companies in the course of prospecting known deposits with drills, but a general revival of prospecting new areas by individuals did not ensue.

Why did not prospecting revive to the same extent that mining did? For the same reasons that have been given earlier, chief among which are the following: For each ounce or pound of metal removed, the odds of finding more became less favorable. As the standard of living gradually improved, men were not used to the discomfort accompanying the prospector's life. After a number of years had gone by without anyone's getting rich overnight by discovering a mine, men began to lose faith in its happening to them. Transportation had improved to the point where men working in the mines during the summer could get out for the winter without much trouble, so much of the prospecting which had been done during the winter when the men were otherwise unoccupied was discontinued. This lost factor was especially true during the latter half of the period after the airplane had become commonplace. After that, no one traveled across country; if a man wished to go somewhere, he flew and saw little of the country he traversed.

Important Events In The History Of Alaskan Mining

Some important events in the history of Alaskan mining are listed below. This list is not complete; very probably it omits some important events and includes some that are unimportant. It is often difficult to judge the relative importance of events, especially for the very early and very recent times. It does, however, provide an idea of the major lines of development. The more important dates are underlined.

1849

Peter Doroshin, Russian mining engineer working for the Russian American Company, mined coal on Cook Inlet and prospected for gold on Russian River, Kenai Peninsula. Otherwise, Russian American Company was indifferent or hostile to mineral development.

- 1862 Buck Choquette found placer gold in small amounts on the bars of the Stikine River.
- 1870 Placer gold found around Sumdum Bay, southeastern Alaska.
- 1871 Placer gold found in the Cassiar district, northern British Columbia, bringing many prospectors to the Alaskan Coast.
Placer gold found near Wrangell, southeastern Alaska.
- 1872 Gold quartz found near Sitka; named "Stewart Mine."
- 1873 Two parties, headed by Arthur Harper and Jack McQuesten, reached the Yukon Basin via the MacKenzie River.
- 1875 Placer gold found on Shuck River, Windham Bay, southeastern Alaska,
(approx.) reportedly by Mix Silva.
- 1875 Upper Yukon reached by Chilkoot Pass for first time.
- 1877 5 Stamp mill erected at Stewart Mine.
- 1879 John Muir and S. Hall Young explore southeastern Alaska Coast south of Glacier Bay, reported geology favorable for gold lodes.
- 1880 Joseph Juneau and Richard T. Harris, grubstaked by George E. Pilz of Sitka and Hull Brothers of San Francisco, discover placer and lode gold at present site of Juneau.
- 1882 First stamp mill at Treadwell Mine, Douglas Island.
First stamp mill on the mainland, at Ebner Mine, Juneau.
- 1884 Lode gold found at Unga Island in southwestern Alaska.
- 1886 Lode gold discovered at Berners Bay, southeastern Alaska.
- 1886 Howard Franklin finds gold on Fortymile River and on Franklin Creek.
- 1887 Beach placer gold mined at Yakutat Bay and Lituya Bay.
- 1888 Placer gold found on Resurrection Creek, Kenai Peninsula.
- 1893 Pitka and Sorresco discover placer gold on Birch Creek (Circle District).
John Mynook discovers placer gold in Rampart district.
Placer gold found on Tramway Bar, upper Koyukuk.
- 1896 Placer gold discovered in Klondike district, Y. T., independently by Robert Henderson and George W. Carmack.
- 1897 Placer gold found on Ophir Creek, Seward Peninsula.
- 1898 Klondike stamped.
- Placer gold found in Porcupine district near Haines.
- 1898 Placer gold found at Nome, Seward Peninsula by Jafet Lindeberg, Jon Brynteson, and Eric O. Lindblom.
Kobuk Stamped.
- 1899 Upper Koyukuk placers discovered.
- 1899 Nome beach gold discovered.
Copper discovered at Kennicott.
- 1889-1900 First shipments of copper from Prince William Sound.
- 1900 Placer tin found on Seward Peninsula.
- 1902 Placer gold discovered in Tanana (Fairbanks) district by Felix Pedro.
- 1903 Placer gold discovered in Bonfield district.
Placer gold found at Denali (Valdez Creek) on upper Susitna River.
Lode tin discovered at Lost River, Seward Peninsula.
- 1905 Placer gold found in Kantishna district.
Copper mining on Prince of Wales Island begins.
Copper smelter begins three years of operation at Hadley.
- 1906 Placer gold found in Tenderfoot district.
Placer and quartz gold found in Chandalar district by Frank Yasuda and Thomas G. Carter, partners.
Gold in quartz found in Willow Creek district.
- 1906-07 Placer gold found on Ganes Creek, Innoko district.
Placer gold found about this time in Talkeetna (Yentna) district.
- 1907 Placer gold found in Ruby district, although little activity until 1910 when gold discovered on Long Creek.
Gold discovered on Nolan Creek, Upper Koyukuk district.
- 1909 Placer gold discovered in Iditarod district by John Beaton and W. A. Dikeman.
Placer gold discovered on Klery Creek, Kiana, Kobuk district.
- 1910 Placer gold discovered near Hughes, middle Koyukuk.
- 1900-1914 Lower Kuskokwim, Arolik River and Wattamus Creek stamped several times.
- 1910 Gold bearing quartz found at Valdez.
- 1910-1920 Several mercury deposits found in Kuskokwim region.
- 1911 Placer gold found on Hammond River, Upper Koyukuk.
First copper shipped from Kennicott.
- 1912 Placer gold discovered at Chisana (Shushana).
- 1913 Placer gold discovered at Nelchina.
Placer gold discovered at Marshall, lower Yukon.

- 1914 Placer gold discovered in Tolovana district (Livengood).
- 1915 Large scale gold quartz mining started at Juneau.
- 1916 Chromite shipped from Red Mountain and Claim Point, Kenai Peninsula; these were discovered before 1909.
- 1918 Premier Mine in British Columbia, across border from Hyder district discovered, accelerated prospecting in Hyder district.
- 1924 Alaska Railroad completed, bringing rail transportation to the Interior; coal mining in Interior made possible.
- 1924 Large scale dredging program at Fairbanks planned.
- 1926 Placer platinum discovered at Goodnews Bay: small scale mining until 1934 when mining with mechanical equipment began.
- 1930 Gold in quartz discovered at Nabesna.
- Copper mining in Prince William Sound ended.
- 1933-34 Price of gold increased from \$20.67 to \$35.00 per ounce.
- 1941-45 Intensive investigation by Federal and Territorial agencies of known strategic mineral deposits.
- 1942 Gold mining prohibited by law because of war.
- 1943 Oil exploration started in Arctic; private oil exploration prohibited.
- 1945 Gold mining again allowed by law.
- 1945 War ended, inflation adversely affected resumption of gold mining.
- Private oil exploration allowed.
- 1952 Exploration of copper near Shungnak, Kobuk by Rheinhardt Berg and others.
- (approx.)
- 1953 Arctic oil prospecting by Navy ceased, increased oil prospecting by private companies.
- 1955 Uranium discovered on Prince of Wales Island, southeastern Alaska.
- 1957 Oil found on Kenai Peninsula.
- 1963 Kobuk copper property purchased by Bear Creek Mining Company.

References

- Amero, Alfred, Personal Communications (See Photograph, p. 175.)
- Brooks, Alfred H., 1952, Blazing Alaska's Trails, University of Alaska-Arctic Institute
- Grinnell, Joseph, 1901, Gold Hunting in Alaska: David C. Cook Publishing Co. Chicago
- Hildebrandt, James, 1942, History of Placer Mining in Alaska: Unpublished paper, University of Alaska
- Parker, Genevieve, 1929, Evolution of Placer Mining Methods, Alaska: Unpublished thesis, University of Alaska
- United States Geological Survey Publications, 1900-1955

Chapter 9

GENERAL PROSPECTING

DEFINITIONS

Before continuing with this chapter, the reader should understand the following terms:

Prospecting - Searching for a mineral deposit. In general usage, it also means the procedure of determining the boundaries of the ore body. Many authorities, including Peele, use "exploration" for this latter procedure. It is so used here.

Exploration - Determining the outlines of an ore deposit after prospecting has found it. The word exploration is used very little among prospectors in Alaska, who use prospecting to cover both meanings. It is always necessary to differentiate between the two. On some ore bodies (e.g. many placers), prospecting and exploration are carried on simultaneously.

Development - Making openings in preparation for extracting ore.

Mining, exploitation - The extracting of ore. In underground lode mines exploitation usually consists of "stoping."

Stoping - Extracting ore from a lode underground.

Prospect - A mineral deposit before exploration has proved it worthy of development.

Ore - Naturally occurring material which can be mined at a profit, usually restricted to material containing metallic minerals, but occasionally the meaning is expanded to include nonmetallics, as sulfur.

Ore shoot - A body of mineable material (ore) within a lode.

Mine - An ore body which is producing or able to produce ore.

Back - The space above a horizontal opening in rock.

Lode - Strictly, a mineral deposit filling a fissure; more generally, a mineral deposit occurring in place; not a placer; synonymous with "hardrock deposit."

Placer - A mineral deposit in unconsolidated material, usually gravel, the valuable minerals of which were broken from the rocks and deposited at the same time as the gravel.

Camp - A mining district.

Stampede - A rush of men to a new mining camp, real or supposed.

Other definitions are given in this chapter as it progresses.

PRELIMINARY TO FIELD WORK; FACTORS AFFECTING CHOICE OF AREA AND COMMODITY SOUGHT

Whether or not the prospector realizes it, all prospecting ventures start with a very general objective, and systematically proceed toward a particular one. The general problem which presents itself at the outset is to find a valuable deposit of mineral, any mineral in any kind of geological setting, anywhere in the world. Seldom, however, is a prospecting program set up with so broad a purpose, and then only by large companies. Because this book is concerned with the Alaskan prospector, it presumes that he is interested in prospecting only in Alaska. Because of economic necessity, personal inclination, special knowledge which he believes fits him for exploring a particular region, or for some other reason, the prospector usually limits his field to some restricted area of Alaska. Of this area, he may eliminate a part, such as the Yukon Flats, because of broadly unfavorable geology, leaving a still smaller area in which to prospect. If the prospector is one of the first men to prospect a region, he will have no partiality toward any part of it, and he will probably choose the most accessible part. In these days most parts of the country have had at least a cursory investigation, and the most obvious mineralized areas have been found. The prospector, even unconsciously, is guided to a particular area by what he hears of the results of such earlier investigations.

Usually, however, the prospector makes a conscious effort to determine the most favorable area by consulting the literature on the area, particularly U. S. Geological Survey Bulletins. Next, the stories of older prospectors are pieced together, or the region located where actual discoveries have been made and efforts directed toward it. Thus, by taking advantage of what others have done, the search is narrowed to a restricted area before the prospector begins.

The results of his investigations into the history of his chosen area may lead the prospector to a particular lode system or creek, or even to a particular part of the lode system or creek. The following example illustrates how the experience of others may lead to a particular part of a creek: A line of shafts was sunk with indifferent results, and, as often happens, the original prospector left the creek without completely crosscutting it. It only remains for the new prospector to finish the crosscut to learn a great deal about his creek with little work.

Not only in his selection of an area is the prospector guided by the experience of others. The questions of whether to search for lode or for placer, for gold, platinum, or base metals may be decided by the early history of the district. An area may be known to be favorable to copper or to lode gold or to placer gold, and this knowledge is kept in mind when planning the prospecting. An area containing mines that have produced or are producing is always a favorable place to look for new deposits. It should be remembered, however, that if a mine has been shut down, there is always a reason. It should never be assumed that new ore bodies might exist in or near the mine or that work can be resumed at a profit unless there is definite evidence in the form of samples and assays. As McKinstry points out, most mines are not shut down when the tenor of the ore first drops below commercial grade. Work continues usually for several more months until all reasonable possibilities have been completely exhausted. Also, a company mining a deposit is in a better position to prospect the surrounding area than a man moving in after the mine has been shut down.

From the foregoing, it is evident that the prospector may begin his work at almost any stage, from a general reconnaissance through a new country to the detailed exploration of a particular portion of a creek or vein.

Even before choosing an area, the prospector should consider a few economic factors about different minerals and types of deposits (some of which were discussed in Chapter 8). Because gold (and platinum) present no problem in transportation to the market, transportation need be arranged only for the mining materials and supplies -- one way transportation. The farther from cheap transportation that the prospector penetrates, the greater becomes the importance of gold or platinum relative to base metals.

In Chapter 8 it was pointed out that generally the search for base metals represents a better investment of time south of the Alaska Range than north of it. Again it must be reiterated that this generality, though true, does not rule out the possibility of valuable base metal deposits being found in the interior. Essentially, the higher the transportation costs, the higher must be the value of the material mined. Base metals fluctuate in price, but barring major technical discoveries, there is a permanent general price structure in which some are more valuable relative to others. Using 1964 prices, the importance of price can be illustrated with a few examples: Lead is worth \$0.13 per pound; pure galena is worth approximately \$0.09 per pound, or \$180 per ton in Idaho. Zinc is worth \$0.13 per pound, but pure sphalerite is worth only \$0.04 per pound, or \$80 per ton in Missouri. If copper is worth about \$0.30 per pound, pure chalcocite is worth about \$0.09 per pound or \$180 per ton; pure chalcocite, about \$660 per ton in Washington. Mercury is worth \$220 per flask of 76 pounds, or \$2.90 per pound, or \$5800 per ton. Mercury as an object of prospecting is further enhanced because it is easily produced at the mine, so shipping charges are paid only on pure mercury, not on the cinnabar.

The prices of some metals are artificially supported by the government to stimulate production. When searching for sources of such metals, the prospector must be reasonably sure that the price will be maintained long enough to do him any good. Tungsten ore, for example, which for a number of years sold for \$3.15 per pound of tungsten oxide (WO_3) dropped to considerably less than \$1.00 per pound of (WO_3).

Taking an extreme case, where the transportation charge from mine to smelter is \$200 per ton, as it might be if a long airplane haul were necessary, and where \$75 per ton is required to cover the other costs, a mine producing pure galena or sphalerite could easily operate at a loss. Ore containing one third chalcocite will be worth about \$220 per ton. Because the chalcocite in each ton is concentrated, the shipping charge per ton of ore mined is less than \$100, leaving a profit margin, which, however, might be reduced because of the added expense of concentrating. Tungsten ore, containing less than 5% scheelite, might constitute ore. Gold ore containing three tray ounces per ton or 0.000125% gold would constitute ore, since the shipping charge per ton of ore is almost negligible.

These examples are extreme. If we move the hypothetical location of the mine to tidewater in Southeastern Alaska, where transportation costs are low, or even to water transport farther north, most of the minerals cited above might be valuable ore. Titanium, however, would require careful mining in any part of Alaska, with ilmenite at about \$25 per ton.

What does this tell the prospector? Along the coast, the railroad, the highway system, and to a lesser degree along the navigable rivers, the mining of base metals may be profitable, and they may be of equal or greater importance as an objective in prospecting than is gold. But anywhere air or overland (tractor) transportation is necessary, a base metal deposit must be very rich to support mining. Therefore, in many places in Interior Alaska, far from markets as it is, the most feasible mining, economically, is for gold. Similarly, the high value base metals or nonmetallic commodities such as tungsten, mercury, or asbestos require less expenditure in transportation cost per unit of value produced. These products have an advantage over low value commodities, but the farther from transportation that they occur, the higher must be the grade of the commodity. One factor should not be overlooked, however: A base metal mine that can be worked at a profit provides a backhaul to the continental United States and may reduce transportation costs to some extent; this fact improves the chances for further base metal mining.

To make a profit, the metals must also occur in sufficient quantity so that the higher initial cost of development due to inaccessibility will be paid back and enough left to provide for a profit before the mine is worked out. In certain areas, of course, where a particular metal is known to occur, as copper in the Copper River region or mercury in the Kuskokwim region, gold may be only a secondary objective. (See metallogenetic provinces, Chapter 7).

The factor of price fluctuations must not be overlooked. Gold, with its fixed price, is at a disadvantage during boom times, but becomes more valuable during depressions. If a gold mine can be worked at a profit during boom times obviously it will be valuable during depressed times. Base metal deposits, on the other hand, which are profitable during boom times, may be shut down during a depression unless the deposit is very rich. The subject of artificially maintained price has already been mentioned.

The prospector, therefore, decides on the area in which he will work; and if the area is not a known metallogenetic province for some base metal, the search for gold is his chief aim, although he bears in mind that anything of value which he discovers will be investigated. His first step is to visit one of the offices listed in the Appendix of this book and to consult the U. S. Geological Survey bulletins and other publications referring to his area. This literature gives him a general picture of the geology and history of the region. Next, he contacts any men who have been in the region and obtains what information he can from them.

RECONNAISSANCE

Since at this stage the prospector has no specific creek or lode in mind, he starts with a reconnaissance (undetailed examination) of the area, which must be made in the summertime after all of the snow has melted and preferably after the ground has had a chance to thaw. If the prospector plans only a few weeks' work, he can be landed by float plane on a nearby lake after the breakup and pack his supplies to his headquarters. For a trip of all summer, however, too much time would be consumed in packing, and it is best to have supplies dropped or landed on the ice of a lake in the early spring before the breakup. (See Chapter 14.) Supplies can then be hauled and cached at the headquarters or in different spots in the country. If navigable streams flow through the area, supplies can be brought in by boat or canoe, but this method also consumes valuable time, unless the boat itself is to be the headquarters.

If a large area is to be covered, large widespread indications or "targets" are searched for. In Chapter 7 it was pointed out that deposits tend to occur near small outcrops of igneous rock, so the prospector is always on the lookout for small outcrops of such rocks. Even if igneous rock outcrops are not seen, direct evidence of mineralization should also be watched for. Many lode mineral deposits in Alaska take the form of mineralized quartz veins; and quartz float, which can be traced easily to the outcrop, or the outcrop itself, are direct evidences of mineralization that often are as easy to detect as the indirect evidence of igneous rock outcrops. Unfortunately, barren, unmineralized "bull" quartz usually tends to persist as outcrops or large chunks of float, whereas mineralized quartz often disintegrates readily. In this early reconnaissance stage of the work, anything that looks different or out of the ordinary should be examined, because mineralized or sheared rocks or igneous outcrops may weather at a different rate from the surrounding rocks. This interest in features which attract attention by their different appearance is a natural curiosity which usually need not be cultivated by the prospector.

Other, more widespread signs of mineralization than quartz veins may be found, however:

1. Oxidation products and mineral stains
2. Mineral springs and incrustations
3. Cellular structures
4. Alteration zones
5. Shear zones.

Whether or not igneous rock outcrops or other general signs of mineralization are noted, the prospector should pan each creek he encounters. First, he walks the length of the creek, trying to find a place where bedrock is exposed. If such a place is located, gravel should be panned from different places, especially from any crevices which might exist in bedrock. If any gold is present in the area drained by the creek, some should be found in this way. An unusually large amount of any other mineral, such as chromite or galena, in the concentrates should warn the prospector to be on the lookout for hardrock deposits of these base metal minerals.

If no exposed bedrock is found on the creek, the prospector proceeds to a place near the head of the creek, where it is assumed that bedrock is not very deep and where the valley is fairly narrow, and digs a shallow drain. Loose rocks are thrown out of the stream, and the water is allowed to carry away the fine material exposed by the removal of the rocks. Gravel which has been washed free of fines is then shoveled out, the shoveling always being done upstream, removing rocks and loose gravel and leaving that part of the stream behind him running at a flatter grade than originally, until his drain has attained a depth of approximately two feet, or until he is through the loose material of the surface. (See Fig. 9-1.) Because he removes only washed gravel and rocks, any gold or other mineral which was lodged in the space now occupied by the drain is still on the bottom. Several pans are then washed from different



Fig. 9-1. - Groundsluicing a Preliminary Drain to Get Below Loose Gravel.

places in the drain. Because the drain may be quite a distance above bedrock, it should not be expected that any but very small amounts of gold will be found, and the presence of one or two specks of flour gold should encourage the prospector. This process, when carried out on a bigger scale, is called "groundsluicing" and is described in detail in Chapter 12.

Gold or other indications of mineralization found in the creek may justify the prospecting of the creek for placer. In fact, the presence of general signs of mineralization, such as small igneous intrusions, altered rocks, mineral springs, etc., is usually enough justification for a more detailed search for placer, if the creek has not been glaciated. The procedure to be followed if it is decided to prospect the creek for placer is described in Chapter 12, but here the preliminary search of the area is continued.

Several shallow drains should be dug and panned at intervals up the creek, because the surface gold comes from rock which is being eroded at present, and the position of such gold in the creek may give some indication of the location of lodes in the area. The fine gold may be swept down the creek from its head, or it may be coming down the valley sides. If the amount of surface gold in the streams drops off sharply as the stream is ascended, a search is made up on the valley sides for float, or the valley sides are panned to determine if any gold is coming down them. If float quartz or gold is found, the source should be sought straight uphill.

References

- Fay, Albert H., 1920, A Glossary of the Mining and Mineral Industry: U.S. Bureau of Mines, Bull. 95, 754p.
McKinstry, Hugh E., 1948, Mining Geology: Prentice Hall Inc., New York., 680p.

Chapter 10

PROSPECTING AND EXPLORATION OF LODS

PROSPECTING

In Chapter 9 the preliminary stages of prospecting were described. It is assumed enough general evidence of mineralization has been found to lead the prospector to suspect the presence of lodes in the country. In searching for such a lode, the prospector first walks the ridges where bedrock is exposed. (A good pair of field glasses may save a lot of walking). Failing to find a lode outcrop where bedrock is exposed, the prospector digs through the overburden on the basis of some surface evidence. Float should be searched for diligently, for where there is float, the lode must be nearby unless it has been worn away. Dirt and rocks brought up by animals such as ground squirrels and marmots should be examined. Willows aligned on a hillside in a way different from normal drainage (other than straight down the hill) indicate a water course which may be following a shear zone or vein system. Therefore, any growth of vegetation which indicates more moisture than normal should be investigated.

The habit (or mode of occurrence) of the lodes in the area under investigation should be ascertained if possible, for if one vein or lode exhibits certain peculiarities, others may also. For a known district, these peculiarities may be found in the literature or from men who have experience in the district. When known, certain specific aspects of habit should be watched for. As an example, some veins weather faster than the surrounding country rock, and where such veins cross ridges, definite notches or saddles develop. In some districts the veins bear a certain relationship to some structural features, but this relationship may not be of any use unless the structure can be mapped. An example of such structural relationship is the occurrence of scheelite at the intersection of limy beds with igneous intrusives in the Fairbanks district.

The Mining Engineers' Handbook, by Peele, sums up the conditions justifying prospecting (by permission from Peele, Mining Engineers' Handbook, 1941, John Wiley and Sons, Inc.) as follows:

1. Presence of outcrops
2. Presence of float as pieces of ore or specks of metal
3. Favorable geological conditions (This condition covers a great deal of indirect evidence).
4. Ancient workings (This condition does not apply to Alaska except when it is desired to find where certain tribes obtained their copper or jade).

If float has been found on a hillside, the slope should be examined for more. Float coming down a hillside fans out from the source. Several pieces of float may form a wedge pointing uphill toward the approximate location of the source. If the vein is parallel to the trend of the hillside, it will spread float over a large area, and it is only necessary to work uphill until float is no longer encountered. When a point is reached where it is believed the lode will be found in place, a narrow trench should be sunk to bedrock so that it crosses the supposed strike of the lode at a right angle. In prospecting or exploring for any deposits, the prospector should always proceed in a direction at right angles to the strike or supposed strike. (This is called cross-cutting). After a deposit is found, it may be advisable to trench parallel to the strike, but only after the vein has been found in spots by crosscuts spaced some distance apart.

Up to this point, the strike of the vein is unknown, but a guess can be made, guided by the available evidence. Usually trenches or pits sunk in search of such a lode are on a hillside or on top of a ridge, where the overburden is residual soil or slope creep, which grades downward into bedrock. As the trench nears bedrock, vein float is encountered, grading into the vein. When the vein in place is found, it should be uncovered enough to expose the entire width and so enable the prospector to measure the strike and dip. A sample should be taken from across the vein at this time because the pit will not remain open unless the trench is cribbed, which usually is too expensive to apply to a prospect pit.

EXPLORATION

The existence of a vein or lode in place has been established and the dip and strike measured at one point. Still, unless the lode is very rich, it is not known if ore exists because the value of the material depends not only upon the amount of mineral contained but also upon the amount available. Assuming, however, that the first trench uncovers sufficiently rich material to be interesting, work now passes from the prospecting to the exploration stage, and the first exploration is done by tracing on the surface. If the surface is level or if the vein has a vertical dip, the vein may be followed simply by digging along the direction of its strike. If, however, as ol-

most always happens, the ground surface is irregular and the vein dips at some other angle than verticle, the path along which the vein will intersect the surface is irregularly curved. A little reflection indicates in which direction it curves. Assume a vein striking east and west and dipping south. If, in going along the vein the ground rises, points on the vein are reached which are farther north. The higher the elevation, the farther north the intersection of the vein is with the surface. Similarly, at a lower elevation the vein intersects the surface farther south.

If the prospector stands on the vein, facing with the strike, and looks at rising ground, he can estimate the position where he should dig to find the vein. He drives two poles into the vein so they are leaning at the same dip as the vein and sights across them. Because they lie in the plane of the vein, the path of the vein on the hillside can be traced by sighting across the two poles. Bearing in mind that the vein is not a true plane and sighting across rough poles introduces some error, the prospector, nevertheless, gets a rough idea where the next trench should be started. The second trench should not be more than 100 to 150 feet away from the first.

If a Brunton compass and tripod are available, this tracing of the path of a vein up or down a hill can be accomplished more accurately. The compass is mounted on the tripod over the vein and lined up along the strike of the vein. The compass is then tilted so that the long axis of the compass still points in the direction of the strike, but it is no longer horizontal; it has the same dip as the vein. The flat plane of the compass now lies in the plane of the vein, and by rotating the compass on the tripod the line of sight of the brunton follows the path of the vein. (See Fig. 10 - 1.)

If the vein is found in the second trench, it is sampled, and a third trench started. If it is not found in the trench, the prospector retreats half way to the first trench to locate it there. If it pinches out, a little time should be spent trenching farther on to see if it swells out again. It should be followed in the other direction to determine if it pinches out there, too. If the vein has been faulted off, more trenches are dug until the point where the vein faulted off is located. There are then two facts which must be determined: in what direction did the vein move and how far did it move? Both may be difficult to determine. First, the surface is scouted for signs of float that might indicate the presence of the faulted extension. If no evidence is uncovered, this



Fig. 10-1 - Brunton Compass Set Up for Tracing Vein.

way, the fault on both sides of the vein is uncovered and examined for drag ore or pieces of vein material dragged along by the faulting. A slight bending of the rocks (drag) indicating the direction of movements may be observed at the fault, especially in bedded rocks. The slickensides also may indicate the relative direction of movement. (See Chapter 3.) Complementary shears are shear planes crossing the fault diagonally. Where they occur, the acute angle points in the direction of wall movement. Finally, the displacement due to faulting in one mine or area often is predominantly in one direction; thus in the Cleary Hill mine near Fairbanks, the amount of displacement can only be determined by searching for float and by trenching. (These remarks have assumed that trenching is done with pick and shovel. If a bulldozer is available and can reach the prospect, its use will produce many times the results for the same money).

Veins have barren parts and mineralized parts. If a barren vein is found in an outcrop, it is usually worth sinking two or three pits along it to see if an ore shoot can be located. If the vein remains barren at these two or three spots, however, it is best to discontinue prospecting, unless other veins in the district provide information which leads the prospector to think an ore shoot exists.

How far should surface prospecting of this type be carried? Probably until the depth of overburden reaches eight feet or so, depending upon the ease of digging. If a bulldozer is available and can be taken to the outcrop, depths of twelve to fifteen feet can be reached easily. When the easily accessible parts of the vein have been outlined by surface work and to go farther would entail digging through overburden that exceeds a reasonable depth, it is time to seek a buyer for the property or to begin underground exploration. A prospector should never begin underground work until all surface work which can be accomplished by reasonable effort is done, if his purpose is strictly prospecting. (If he wishes to operate a small mine and extract ore, however, he may begin underground development work sooner). One man, digging small trenches along a vein, may trace a vein a thousand feet horizontally and several hundred feet vertically (if the vein follows down a hillside), in the same time that he might be sinking or drifting ten or twenty feet underground. Ten or twenty feet of proved vein do not make a mine; a thousand feet probably will. Eventually the underground work must begin, but it is expensive, and the surface work should have removed most of the risk from the venture.

So far in this discussion it has been assumed that the ore body is a vein. What is best to do if it is some other type? The primary purpose of exploration is to find the limits of the ore after it is found in place. If the deposit is a dike, it is treated as a vein. If a flat lying bed, the outcrop on a hillside may be traced so far as possible by surface trenching, after which holes may be sunk or drilled from above. When the depth of cover becomes excessive, there is no alternative but to begin drifting underground. Before underground work is begun, an attempt should be made to arrange the openings so that they can be used to bring out ore later, should the prospect develop into a mine, but a prospector should never leave the ore and begin drifting through country rock in the hope of striking the ore body at a new place and at the same time make an opening through which to bring out ore. Such an opening may be made after the ore has been proven, when it can be calculated that the new opening will pay for itself in cheaper ore handling, but not before.

If the deposit is an irregular replacement deposit, planning the exploration is more difficult. In laying out the trenching program on an irregular ore body, the prospector should be systematic and measure the distance between trenches. A straight line is laid out along what is thought to be the long dimension and cross lines laid off at right angles at equal intervals, the intervals depending on the size of the ore body. Trenches or pits are then dug along the cross lines until the edge of the ore is found. If the ore can only be identified by assaying, assays must be made as the work progresses.

Perhaps the most difficult type of deposit to explore is a replacement lode which is merely a mineralized zone in the country rock. The factors which caused the valuable mineral to be deposited in the zone may not be apparent. Usually, however, pronounced alteration of the rock, or presence of some distinctive mineral indicates the valuable mineralization, or the sulfides which are often part of the ore may be abundant enough to allow the ore to be followed. Even so, the actual limits of economic mining may have to be determined by assaying (assay limits or assay walls). An example of this is a scheelite deposit at Gilmore Dome, Fairbanks District. The ore zone can be recognized by its different appearance, but the ore itself must be traced with ultraviolet light.

SUMMARY OF SURFACE PROSPECTING AND EXPLORATION METHODS

The following summary of surface prospecting methods is taken from Peele's Mining Engineers' Handbook (with permission of the publishers). Some of these methods have not been mentioned before, but they are simple methods which require little explanation.

1. **Tracing Float.** This method is applicable to durable ores (quartz) on hillsides, where the hillside creep is great and where float may be found far downhill from the source. Some idea of this distance may be obtained from the appearance of the float, very sharp and an-

gular quartz being close to the source, quartz with rounded edges being away from the source. This material is not so rounded as creek gravel; it is simply weathered slide.

A vein on a hillside provides float which works downhill, but this float does not appear on the surface until it is some distance downhill from the vein. As it is being followed uphill, the point at which it disappears is the point at which it is said to go down. On flat slopes with little overburden, float may be found very close to the vein; on steep slopes it may go down several hundred feet below the vein. (See Fig. 10-2 and Fig. 10-3.)

Float in glacial debris means nothing.

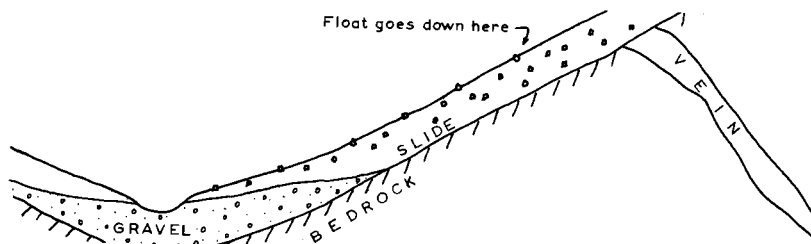


Fig. 10-2 - Relationship of Float to Vein on A Hillside.

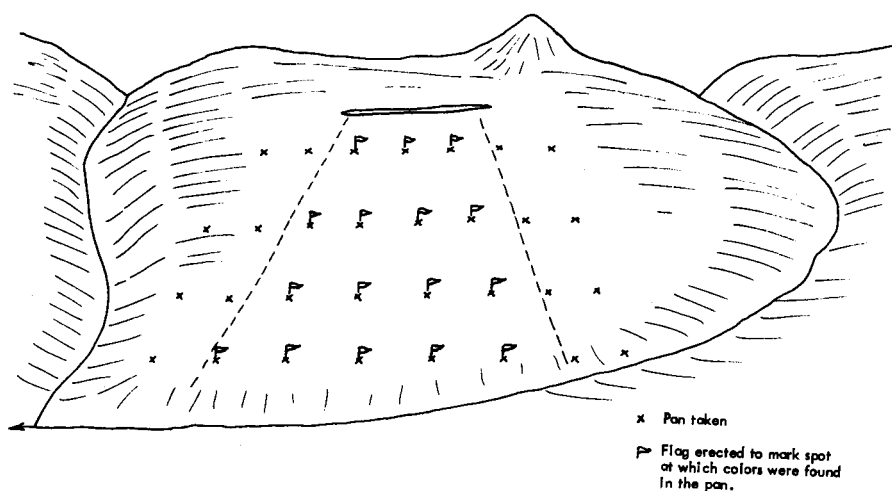


Fig. 10-3 - Locating Lode by Panning.

2. Tracing by panning, or tracing (loaming in Australia). This procedure is actually tracing float, but in this case float consists of specks of metal. It is done in the same way as tracing float; pans are taken at intervals along the bottom of a hill, high enough to be unaffected by creek wash. Where colors or bits of sulfides are found or noted to increase, a marker is set; and where colors cease to be found, or where they decrease in amount, another is set. This process is repeated along contours up the hill; the markers are followed to the source, toward which they should converge. This method is best applied to gold, but may be used for sulfides. (See Fig. 10-3.)

3. Vegetation Changes. Some rock types or structural features favor certain vegetation, so contacts and fissures may be traced from vegetation changes. The ultrabasic rocks in which are found platinum at Goodnews Bay and Chromite on Kenai Peninsula may be quickly located because little or no vegetation grows upon them.

4. Material brought up by burrowing animals. This material should be examined as it may indicate float under the vegetation cover.

5. Trenching. This is usually an exploration method but is applied to prospecting for a new mineral deposit in connection with some other method such as tracing float. At this stage, before the vein has been found in place, trenches are dug at right angles to each other so that if one is parallel to the strike, the other will cross it.

6. Test Pits. The sinking of test pits is almost always an exploration method, but, like trenching, may be used to locate a lode after float or colors are lost. Pits are dug where the overburden is too deep for trenches to be dug.

7. Hydraulic prospecting and ground sluicing. This method, which will be treated under methods of prospecting and exploration of placer deposits, is sometimes effective in prospecting for lodges on hillsides. Supplementary evidence, such as float, should be found before undertaking much stripping.

8. Booming or splashing. This application of water will be considered under placer prospecting methods.

9. Driveways. A pipe with a sharpened and tempered cutting edge is driven to bedrock and a sample brought up. This technique is restricted to overburden free from rocks. Sometimes augers are used instead of driveway.

10. Piercing. If the mineral sought is harder or softer than the country rock it can be detected by a pointed rod driven to bedrock. Upon reaching a different material, the rod gives off a distinctive sound when struck with a hammer. In the Eagle River district northwest of Juneau, where the ground is covered with drift, early prospectors determined the presence of quartz veins by this method.

11. Geophysical methods. Geophysical methods are only supplementary to other methods, and even then are principally used in the exploration of known deposits. They are, in general, too expensive to apply to an area in prospecting for a new ore deposit, and in addition, usually give indirect results, which mean little unless correlated with geological findings. Magnetic and radiometric methods applied to the search for magnetite or uranium minerals, are exceptions to the above statement in that the correlation between geophysical observation and ore deposit is more direct and positive.

12. Geochemical methods. These methods are not mentioned in Peele simply because they have been developed since his last edition was published. Unlike many geophysical methods, they are not too expensive for the individual prospector, and they give direct evidence of an ore deposit. Briefly, they consist of making analyses of soils, water, rocks, or vegetation by methods which can detect very minute percentages of many ore minerals. These methods are used exactly as panning is used to trace specks of metal, however, the geochemical analyses detect very much smaller amounts than panning does. Samples are taken on a grid, or along a line, and analyzed; places where increased amounts of ore mineral are found in the soil, water, or vegetation are noted. An ore body completely hidden by overburden may have a "halo" of soil containing one or more ore minerals. After the halo is found by geochemical analysis, the ore body may be located.

13. Mineralogical prospecting methods. A technique applicable to reconnaissance of large areas utilizes the identification of heavy minerals in a stream pattern and the tracing of these minerals back to their sources. Even though the prospector sees only uneconomic minerals, he can detect the possible presence of economic minerals in the district through his knowledge of the association of minerals with other minerals and with certain types of rocks.

Geophysical, geochemical, and mineralogical prospecting are covered more fully in Chapter 15.

Most of these thirteen methods of surface prospecting can be applied to exploration of the deposit after it has been found by prospecting. Prospecting and exploration grade into each other; and as already mentioned, most Alaskan prospectors use the word "prospect" to denote exploration as well as prospecting.

By this time it should be evident that most prospecting and exploration methods are only special tools used in proceeding from the general to the particular.

One of the prospector's most valuable aids, after enough general evidence of mineralization has been noted to justify detailed work, is a map of his area. The simple topographic map, with-

out geology or prospecting results plotted on it, is called the base map. If such a map exists, the prospector plots his results as they accumulate; if it does not exist, he must make one, as described in Chapter 16. Aerial photographs of the area are excellent base maps if they were taken from a low enough altitude to have a fairly large scale. These photographs also provide geographical and geological information which may be of value. Even the small scale pictures taken from higher altitudes provide useful information and in the early stages of prospecting, are adequate as base maps. Plotting of holes, outcrops, values, Geiger counter readings or any other data is the only way in which a true conception of a prospect can be gained.

UNDERGROUND OPENINGS

After all surface work which can be done with reasonable effort has been completed and the prospector wishes to learn still more about his lode property, he must begin underground work. Driving an adit, or a horizontal passage open at one end, is easier and less expensive than sinking a shaft and should be done in preference to sinking where possible. Muck (broken rock) can be wheeled or trammed from an adit instead of being hoisted, water drains out instead of having to be pumped, and working conditions are less cramped and much safer. Although at first thought the adit would seem to be the universal choice, several factors must be considered which often may persuade the prospector to sink a shaft rather than drive an adit. First, if the ground is flat, no adit can be driven. Even if the ground slopes, an adit should not be driven unless the ground slopes steeply because an adit penetrating a gently sloping hill runs almost parallel to the surface and proves little more ore than surface trenching. Ore usually is mined overhead (in the back). An adit should be developed ore in the back, and if only a few feet separate the adit from the surface, little ore is developed. There is an axiom, "Follow the ore, even if it flies up a church steeple", but in following it, the openings should be laid out in such a way as to develop or prove the greatest amount of ore for a given amount of work and expense.

Adits, then, should be run where the ore is found on a steep slope; to drive them into flat slopes is uneconomical. Shaft sinking on a steep hillside, on the other hand, is also uneconomical because the shaft follows the surface of the hill too closely.

On a steep hillside, the same amount of development as that represented by a hundred foot shaft can be accomplished by going down the hill a hundred feet and starting an adit assuming, of course that the vein has already been explored on the sloping surface of the hillside. (See Fig. 10 - 4.)

Shafts

A shaft is started by digging through the unconsolidated material to bedrock, the cross section of the hole being about four feet by five feet. Since this part of the shaft must be cribbed, the finished dimensions are about three feet by four feet. The cribbing is installed as is described for placer shafts. (See Chapter 13.)

DRILLING - Once the shaft reaches hard bedrock, shot holes in the bottom are drilled by hand or machine. If by hand, they are to some extent irregularly spaced to take advantage of depressions and cracks in the rock. If drilled by machine, they are placed on a fixed pattern, although with hand held machines (jack-hammers) some flexibility is possible. A rough rule for the depth of holes is one half the width of the shaft in hard rock to three fourths the width of the shaft in soft rock.

Several patterns of hole arrangement or rounds are used in shaft sinking. The most common is the "V-center" or "wedge". Two rows of holes are drilled parallel to the short dimension of the shaft and arranged so that pairs of holes are formed which angle toward each other to meet at depth along the short axis of the shaft. When these two rows of holes are blasted, they take out a V-cut or wedge. Other rows of holes parallel to the short axis are drilled, those to-

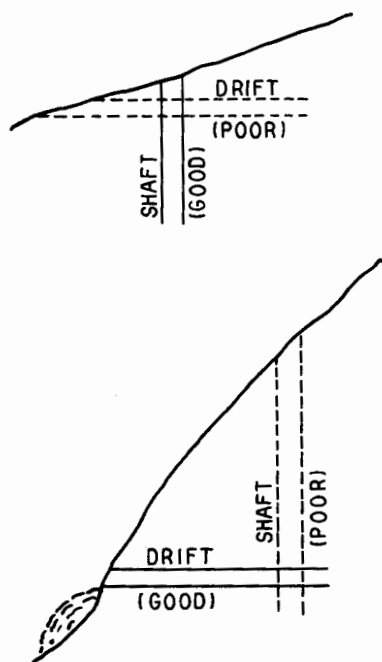


Fig. 10-4. Possible Conditions Under Which Shaft-Sinking or Drifting Might be Preferable.

ward the ends flaring out slightly. The wedge cut is fired first to give an open space for the other holes to break to. In small prospect shafts this arrangement probably will be used; a variety of this system has the wedge at one end of the shaft and rock broken into it from the other end. In any round, the first holes to be fired should make an opening; these are the cut holes. The next holes to fire break material into the cut; these are the relief holes. The last to fire are the trimming holes which bring the openings to the proper dimensions.

Another arrangement of holes is the "pyramid cut". In a circular shaft, concentric rings of holes converging downward are drilled; in a rectangular shaft four holes near the center point toward a common center, forming a pyramid. A hole in each corner, angled out, and one at the center of each side, also angled out, complete the pattern. The pyramid in the center is shot first and the other holes blasted into it.

A third pattern of shot holes used in shaft sinking is the bench or slope cut. Half of the cross section of the shaft is blasted at one time, using half of a wedge cut, to leave a free face and a sump. The next blast leaves the sump on the other side.

Each hole as it is completed is plugged with a wooden stick to prevent its being filled with debris before the dynamite is put in.

A prospect shaft, sunk upon a vein, is more likely to be inclined than vertical. If the shaft is not inclined very much from the vertical, the work proceeds as in a vertical shaft. For flatter angles, however, it may be necessary or desirable to use a different hole pattern. In the bottom cut, three or four rows of holes are drilled, each row in a vertical plane at right angles to the strike of the vein. The upper hole in each row extends about straight ahead on the projection of the shaft; the lower ones slant downward.

Arrangements of blast holes for shaft sinking are shown in Fig. 10-5.

TIMBERING - Inclined shafts are more likely to need timbering than vertical shafts, although less lagging is necessary because rocks do not have a free fall. Timbering is usually done as in vertical shafts, except that the lower side usually need not be lagged. The hoisting bucket must be guided on pole rails on the footwall side of the shaft. In ground that stands well, it may only be necessary to place stulls on the sides of the shaft, supporting caps above. If necessary,

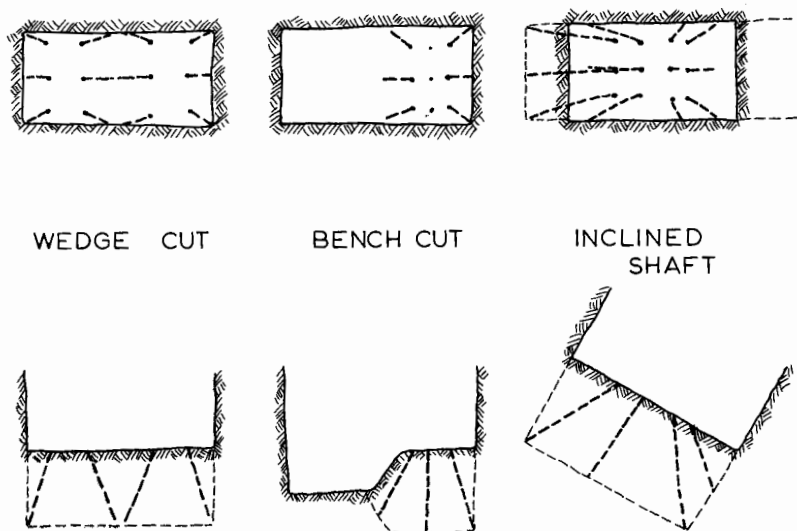


Fig. 10-5. - Arrangement of Blast Holes for Shaft Sinking. The number of holes shown might be adequate for small prospect shafts. Larger shafts might have more holes per row and more rows.

horizontal timbers are set close to the roof in hitches (recesses cut in rock to take ends). All stulls or roof supports are wedged in tightly. Shaft timbering is discussed in more detail in Chapter 13.

Drifts

A drift is a long narrow opening following the vein in a horizontal direction. A cross-cut is similar but at some angle across the vein. A level consists of all the horizontal openings at one elevation. A drift has two walls, a back (overhead) and a floor. A level open at one end is an adit; one open at both ends is a tunnel.

During the first stages of drifting, broken rock is removed from a level, probably with a wheelbarrow running on planks. Later, small rails may be installed so that a car can be used.

DRILLING - Drifting presents different problems than does shaft sinking, although the drilling patterns used are basically the same as those used in shaft sinking. The V or wedge cut round is laid out so the sharp edge of the wedge is vertical and other holes are arranged around the perimeter of the face, or heading. The lowest pair of holes is almost on the floor. The pyramid cut round has the pyramid cut about in the center of the heading with relief and square up holes around it. The common round is the draw cut round, several horizontal rows of four holes each. The lifters, near the floor, slant down and fan out slightly. The holes of the next row above slant down to form a rough wedge with the lifters; this row of holes provides the cut to which the other holes break. Two or three rows of holes above finish the round. In the swing or slabbing round, holes are drilled so that one wall is extended straight ahead, and the face curves into the other wall; the side the curve is on alternates from wall to wall with each round.

The heading and bench round utilizes a V-cut or pyramid cut round to blast out the top half of the face, the heading, leaving the bottom half, the bench, to be blasted out either by down holes or horizontal ones. There are other rounds, and some may have to be improvised to meet special conditions of rock, but those just described are the most common. Also, it should be remembered that in drilling by hand, advantage is always taken of depressions and cracks. Blast hole arrangements used in drifting are shown in Fig. 10-6.

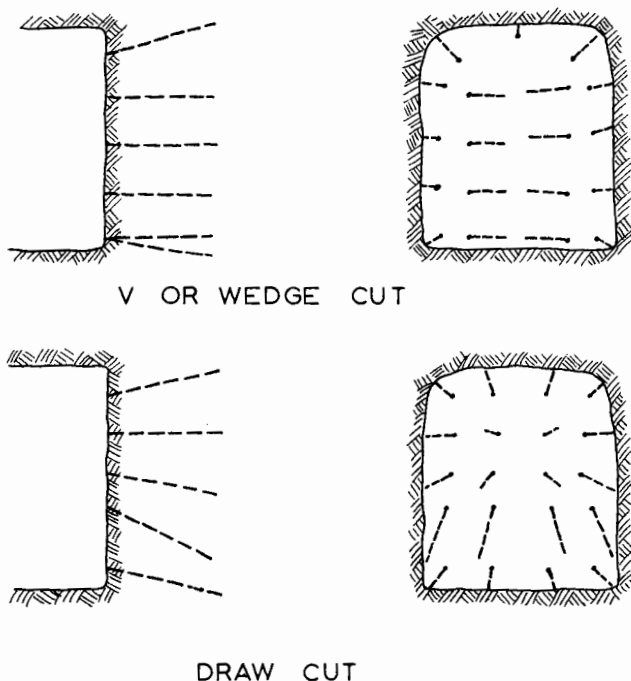


Fig. 10-6. - Arrangements of Blast Holes for Drifting. Only 2 arrangements shown.

TIMBERING - When the drift is in hard dry rock, no support may be needed, but, as is usual when a vein is being followed, the rock is sheared or otherwise weakened, timbering must be used. Even in strong rock, which may stand safely enough during the prospecting stages, timbering must be used if and when development begins, because with exposure to air, most rock disintegrates enough so that slabs may spall off, creating a dangerous condition.

In general, drift timbering consists of sets at equal intervals with lagging outside of the sets to hold out the muck and girts, which keep the sets apart in a horizontal direction. How elaborate a timbering system is used depends on the strength of the ground.

The simplest timbering consists of a lag across the back, inset into pockets, hitches, in the rock. Pole lagging may be laid across several of these to keep rocks from falling down. If these are not satisfactory, three-timber sets may be used. These consist of two posts leaning in towards each other with a cap on top. If any side pressure is anticipated, the posts are kept from pushing in at the top by notching the cap or by nailing a scab on the underside of the cap, against which the posts can push. In swelling ground or where the floor is soft, a sill is set under the posts. Lagging may consist of poles, slabs or planks, and is used in the back or in the back and on both walls, as needed. The girts, horizontal braces tying the sets together, are notched into the posts and caps or held up by scabs nailed to the posts.

In ground which will not stand unsupported, it is necessary to forepole, or drive the lagging ahead of the last set. To do this, the sets are made up with bridges on the posts and caps. These are lighter timbers on the outsides of each cap and each post separated from the timbers of the set by wedges or small blocks. When a set has bridging, there is a space all around it through which the lagging may be driven (between the main timbers and the bridges). As drifting proceeds after each blast, the lagging, or forepoling, is driven ahead from the last set between the bridging and the set. When it reaches about half the distance to the next set, a false set is placed to guide and support it. When it is a full set-length ahead, the next set is built and the false set removed, allowing the lagging to press against the bridging of the new set. After the next round the process is repeated. Of course in this weak ground the sets are close together, about four feet apart. In badly swelling ground, lagging is not set too closely together, spaces being left between poles or planks to allow some material to pass through, thus relieving the pressure on the timbering to some extent. Drift timbering is illustrated in Fig. 10-7.

Winzes

After a drift has been driven along the vein to a point where the prospector is satisfied with its linear extent, he may wish to explore in a vertical direction. To do this he will either sink or raise a winze. If he sinks, the process will be exactly as in shaft sinking; if he raises, he builds a platform and drills overhead. The broken muck after the blast, of course, will fall into the drift below. Winzes usually connect two levels, as it is by winzes and drifts that ore is blocked out.

DEVELOPMENT AND EXPLOITATION

It has been stated previously that underground prospecting should not be undertaken until all surface work which can be done with reasonable effort has been completed. Soon after underground prospecting has started and when it begins to appear the prospect will make a mine, a line is crossed after which development of a mine becomes the aim, rather than exploration of a prospect.

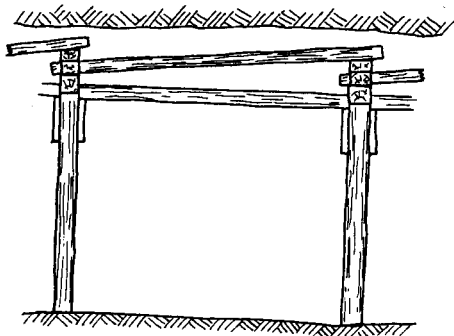
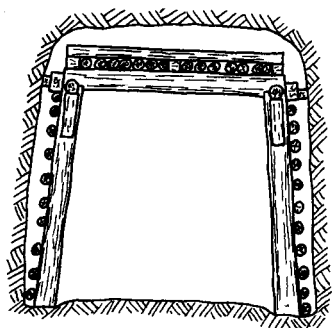
Herbert Hoover in "Principles of Mining" defines some terms which classify ore. They are:

Proved Ore: Ore which has practically no risk of failure of continuity. In veins, no point in the ore should be more than 50 feet from some point sampled. In other words, levels should be no greater than 100 feet apart. In a deposit outstanding for its continuity, this dimension may be increased; in one with a reputation for small ore shoots, it must be reduced.

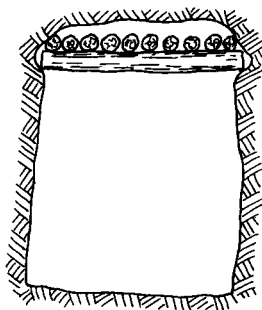
Probable Ore: Ore which has some risk of failure of continuity, yet which presents a warrantable justification for assumption of continuity. Such ore lies beyond the range of proved ore; how far it may be extended reasonably depends on other evidence.

Prospective Ore: Ore which cannot be included under proved ore or probable ore. The further development of the deposit is necessary and although the ore has value, it should not be depended upon. Prospective ore may best be defined as lying in a zone which would be an extremely favorable place to prospect.

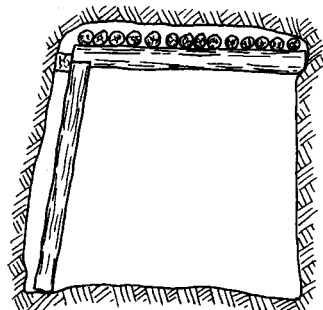
Many engineers object to these terms, preferring to describe ore only as "exposed on 'one', 'two', 'three', or 'four' sides". However, the classifications are useful if it is remembered that they vary with conditions in different districts. How much ore is classified as proved, how much as prospective, and how much as probable, depends upon a knowledge of the habit of the lodes in the district. In mines or districts where the veins are known from experience to contain continuous minerals that vary in value only slowly with distance, it is possible to allow the information gained from a shaft or drift to represent the ore for a distance of 50 feet or more. This ore is then considered proved. Herbert Hoover cites the Witwatersrand gold deposits as examples of



3-TIMBER SET WITH BRIDGES



SIMPLE STULL



HALF SET

Fig. 10-7 - Drift Timbering

outstanding continuity, where ore is considered proved as far as 250 feet from an opening. On the other hand, in some of the gold quartz mines in the Fairbanks district, proved ore cannot be assumed farther than fifteen feet from an opening; if the openings are more than 30 feet apart, some of the ore between them is considered probable or prospective. Obviously if the ore shoots in the area are on the average only about 50 feet in either direction, ore cut by openings 100 feet apart very likely belongs to two different ore shoots, with protore between.

As soon as enough proved ore has been developed to pay for a mill and other costs, leaving the prospective ore for future profit, active mining starts. As this handbook is concerned only with prospecting and exploration, different mining or stoping methods are not discussed. The prospector should know something of such practices, however, so that he may lay out his work with an eye to future mining operations.

The process of extracting all the ore from the lode is stoping. There are many different methods of stoping, but the most important thing the prospector must remember is that in dipping tabular bodies such as most veins and dikes, all ore is removed from the stopes to a lower level. A drift is run along the vein or in the footwall and the ore above it drilled, blasted, and dropped down a chute to the drift. From there it goes to the portal of the drift, if on a side hill, or to a shaft to be hoisted to the surface. If the body is flat lying, the ore will have to be helped to the

haulage level by scrapers; or, if close to the surface, the overburden may be stripped and the deposit mined by open-cut methods.

SAMPLING PROCEDURES AND CALCULATING RESULTS

As each of the pits, trenches, shafts, crosscuts, drifts, winzes, and other openings expose the lode, the prospector is called upon to decide whether the grade of the mineral found justifies further work. In any kind of exploration, this decision should be based upon the most important information that can be secured. This means careful sampling, the results of which allow the prospector to say, "This much material will yield this much value."

The first sampling is necessarily rough and provides qualitative rather than quantitative results. If quartz float is found that looks promising, exhibiting mineral stains and not just glassy or bull quartz, chips are broken off, crushed in a mortar, and panned. If free gold is identified, or any valuable base metal, a search for the source should begin immediately. Any other metallic minerals should be identified, if possible; and if many sulfides are present, another sample should be taken and roasted. This process involves crushing the ore and heating in a frying pan or other container for about half an hour over an open fire to drive off the sulfur, after which the ore is further crushed, and panned. If only gold was contained in sulfides (non free milling) some may be liberated by the roasting; and if a large proportion was so contained, there should be an appreciable increase in the amount of gold recovered by panning after roasting. If there are any unidentified minerals present, a sample should be sent to the State Assayer for identification as soon as possible, with the request that an assay for gold and silver also be made. If float material which might be base metal ore rather than gold bearing quartz is found, the minerals should be identified, their metal content looked up, and the percentage of each mineral present estimated. From this information and a knowledge of the prices paid by smelters for base metals, a rough estimate of the value can be made.

After the lode is found in place, systematic sampling begins. Samples of lode material are evaluated in terms of weight of valuable material per unit weight of ore; precious metals in ounces per ton; base metals usually as a percentage. Consequently in sampling a lode, it is not necessary to measure out a specific weight or volume, but only to make certain that the sample is actually representative of that part of the lode intended. There is only one exception to this rule, and it must be used with an open mind. If, when the prospector first finds a lode, he wishes to decide whether it is worth investigating at all, he may pick a sample of the best looking material to pan or to have assayed, in addition to his representative sample. If the results of this picked sample are not encouraging, he should abandon the prospect. Of course, he should also have his representative sample assayed, for it is possible that the material which he picked as the most promising was actually the least promising ore.

The representative sample of a vein is taken across the width, perpendicular to the strike. There are two kinds: chip and channel samples. A chip sample consists of small chips broken off with a prospector's pick, from a strip four to six inches wide across the vein, the chips all of about the same size and spaced equidistant from each other. The channel sample consists of all the material between the lines which mark the strip to a depth of about a half inch. In hard ore, channel sampling is difficult, and chip samples are adequate, especially if the ore is uniformly mineralized. In soft or spotty ore, however, the channel sample should be cut, usually with hammer and moil (a short pointed piece of tool steel). Samples are caught in a sack, a box, or if there is no danger of loose rock falling and contaminating the sample, on a canvas sample sheet, five or six feet square. Veins uniformly mineralized can be represented by smaller samples than can veins whose mineralization is unevenly distributed or "spotty;" an average for most veins is about one and a half pounds of sample for every foot width of vein. A single sample should not be taken across more than five feet of vein; if the vein is wider, more samples should be taken. If the appearance of the vein changes at some point across its width, the value of the ore may also change there, and each section should be sampled separately. Samples of the wall rock on each side of the vein should also be taken, at least until it has been determined that it contains no values. If the vein is smaller than the opening which is necessary to mine it, samples of the wall rock on each side must be taken, or the wall at least taken into consideration. For instance, if a vein is six inches wide and the drift is three feet wide, two and a half feet of wall rock will have to be removed. If the wall rock contains no values, the values from the six inch vein must pay the cost of mining a three foot wide section. If barren, the wall rock is discarded before milling. If it is evident that the surface ore has been altered in any way, it is best to expose a fresh surface before sampling.

If the vein is exposed continuously, as it will be in drifts or winzes, samples should be cut every five or ten feet. On irregularly spaced surface exposures, this regular sampling, of course, cannot be done. Everything about every sample should be written down in a notebook--including the number assigned to it, true width of vein, length of sample, width of channel, and location. Underground, the location is designated as so many feet along the opening from some reference spot or station, the location of which is known. On the surface a map is made, indicating the location of pits or trenches.

One other type of sample, called a grab sample, is occasionally useful. When sampling a dump of broken ore, the prospector grabs pieces at uniform intervals on its surface, or slightly below its surface if it is weathered. Coarse and fine material should be included in the same proportions in which they occur.

As each sample must represent all the ore half way to adjacent samples, obviously those spaced on five foot centers provide a sounder basis for accurately estimating the amount and value of ore in that part of the deposit sampled than those spaced at ten feet or more. Samples taken at equal intervals simplify the calculations later and provide a more accurate estimate of the value of the ore. (If the sampler were free to vary his locations, he might unconsciously favor the softer ore).

Each sample is transported in a canvas sample sack with a piece of paper inside giving the sample number, which refers to a similarly numbered description in the notebook.

If the sample taken is too big to be transported conveniently, it must be reduced. Care has been exercised to take samples which represent the vein, and equal care must be exercised to see that the value of the sample is not changed during reduction in size. In order to reduce the sample without changing its character, it must be crushed fine enough so that the largest particle is at most one-thousandth the size of the sample. This is done by a mechanical crusher when available; otherwise the sample is crushed by hand.

The ore is broken, piece by piece, with a hammer on a steel block placed in the center of a sample cloth. Some device, such as a section of a tin can, is placed around the ore to keep the chips from flying. The sample may be further crushed in a steel mortar, or if not too large, it may be crushed in the mortar without resorting to the hammer and anvil.

The crushed sample is next rolled on a cloth. It is placed in the center of a piece of canvas, and one after the other of the corners is pulled so as to roll the sample across the cloth. The pull on the folded over corner should be in a horizontal direction for thorough mixing. The ore is now piled in the center by taking material from the bottom and piling it on top so that it rolls down the sides and soon forms a perfect cone. A gold scoop or spoon may be large enough for this procedure, otherwise a small shovel can be used. The cone is then flattened and decimated or quartered.

Decimating consists of taking random shovelfuls, scoopfuls, or spoonfuls, and saving every tenth one, or fifth one, or second one, depending on the size of the sample desired. Quartering, which is more accurate and preferred to decimating, consists of cutting the flattened cone into four equal segments and discarding the two opposite ones. If further reduction is desired, the process of mixing, coning and quartering is repeated until the sample has been reduced to the proper size.

The next step is to ship the samples, each in a sample sack, securely tied and addressed, and with an identifying number inside to the nearest State Assay Office, either at College, Nome, Anchorage, or Ketchikan. If there is some special way in which the results must be returned, as for instance, with a specific airline or by mail to some individual who will forward them, the assayer should be so instructed in an accompanying letter. This letter should also state for what minerals or metals the sample should be assayed.

In a gold-silver assay, all the gold and silver is recovered and reported in ounces per ton. But a small mill, operating on ore from a small mine, will likely recover only the free milling part of the gold and silver by amalgamation. The rest is saved to be extracted later. If the free milling part amounts to 75% of the total and all of it is not saved, it may be that, at least at the start, without installing more equipment, only 70% of the assay value will be saved. As soon as a gold prospect begins to show promise, a test should be run on the ore to determine how much of its gold content is free milling. If the ore contains base metals, this is the time to begin writing to smelters for price schedules.

After all samples have been cut and the assay returns are in, the tonnage and value of the block or ore should be computed. A block of ore is a certain volume of ore, in this case, one represented by the samples. A map or profile of the block is made, with all assays noted in their proper places. This is an assay map and indicates the general shape of the ore shoots in the prospect. To determine the values and size of the ore shoot, however, quantitative calculations must be made. First, each sample must be weighted. This means giving it an importance or weight proportional to its width. A high assay representing the vein at a place where it is two feet wide cannot be directly averaged with a low assay representing a six foot width. The value must be multiplied by the width, giving a quantity combining value and distance in units of assay feet. In very narrow veins the assay inch is used.

Some engineers, before beginning the calculations, reduce any erratically high assay values to the average of those on each side. This method is disputed by others, and the practice must be left to individual judgement, to be followed after reviewing the evidence in each mine. For example, if one or two gold samples out of forty or fifty show abnormally high values, it may be due to the inclusion of a foreign speck of gold. Under such circumstances, it is best to use the average of those on each side or to cut a new sample. In mines where considerable experience has been gained, a reduction factor for such erratic highs may be worked out. On the other hand, in deposits where values are erratically distributed, the high value samples

must be left as found. Samples taken at face value are "uncut" while those which have had their values reduced are "cut." Sometimes the only way to determine the value of ore in which the valuable minerals are distributed erratically is to mill several tons of it.

The following example illustrates the method of calculation. A shaft has been sunk on a vein and sampled every five feet. If each channel is represented by only one sample across its full width, the simple product of (value) times (width) is taken. If, however, more than one sample has been taken from each channel, these must be weighted first. Suppose that from left to right on a vein the first two feet assayed \$105 per ton, the next three feet \$42, and the last two feet \$87 per ton. The weighted assay foot value for the channel is $(2) \times (105) + (3) \times (42) + (2) \times (87) = 210 + 126 + 174 = 510$ assay feet across an eight foot width. Other channels are assumed to run as follows:

Channel	Length Represented	Width Feet	Value Dollars per ton	Assay Feet
1	2.5	8		510
2	5	6	58	348
3	5	4	76	304
4	5	3	47	141
5	5	4	22	88
6	5	3	9	27
7	5	4	18	72
8	5	5	27	135
9	5	6	6	36
10	5	5	9	45
11	2.5	4	3	12
Total		52		1718

The shaft is 50 feet deep, and it appears to have passed through the ore shoot, although the shaft probably will be extended later. To compute the average value of the ore exposed in the shaft, the average width and assay feet of the vein from Channel 1 on the surface to Channel 11 on the bottom are computed. Total width is 52 feet; average width is $52/11 = 4.72$ feet. Total assay feet is 1718 assay feet. The total assay feet, 1718, divided by the total width 52, equals the weighted average value, \$33.04 per ton. The total depth of the block is 50 feet. It is assumed that the assays represent the tenor of the ore for two and a half feet on either side of the channel. All assays represent a length of five feet except the end ones, which represent two and a half feet. (This correction for the ends is sometimes neglected, and the end assays are allowed to represent five feet, making a longer block. In this example the first channel is assumed to be at the top of the ore, so this is impossible.) The area of the vein exposed in the shaft is (average width) \times (length), or $(4.7) \times (50)$ equals 235 feet.

This book accepts as a basic principle that underground exploration of lodes should not be attempted until as much surface work has been done as is practical. In this example, therefore, it is assumed that a trench has been dug by a bulldozer along the vein on the surface and that for a distance of 150 feet from the collar of the shaft an ore shoot exists. Assuming the vein in this trench has been channel sampled every five feet, and the 75 feet nearest the shaft has an average width of 4.2 feet and an average value of \$42.75, and the next 75 feet has an average width of 3.9 feet and an average value of \$33.50. Two sides of a block of ore are now uncovered, and it may be possible to evaluate a triangular block having as legs the trench and the shaft.

Because stoping usually cannot begin until a drift has been driven under the ore, the prospector begins drifting on the 50 foot level. Suppose this drift proves to be 130 feet long, the first 65 feet of which has an average width of 4.6 feet and an average assay value of \$28.25 per ton, and the second 65 feet, 3.5 feet wide with a \$19.50 value per ton. The block of ore is now exposed on three sides. (Round numbers will be easier to follow from now on).

In the example being considered, it is assumed the continuity of veins in the district is such that having outlined three sides of the block, this block contains proved ore. This conclusion is not unreasonable and assumes an extension of proved ore for only twenty five feet. The block now is as represented in Fig. 10-8.

In deciding the amount each opening will influence the total, considerable judgement is required. In general, if any portion of a sampled opening has a much higher value than the rest of the block, its influence should be restricted to a small volume. In this example the influence of the assays in the trench and in the drift are allowed to extend only half way to each other. The influence of assays in the shaft are allowed to extend only halfway to the unbounded edge of the block. This makes dividing the block into block A and block B necessary (see Fig. 10-8). Thus block B is influenced by the trench and drift assays, while block A is influenced in addition by the shaft assays.

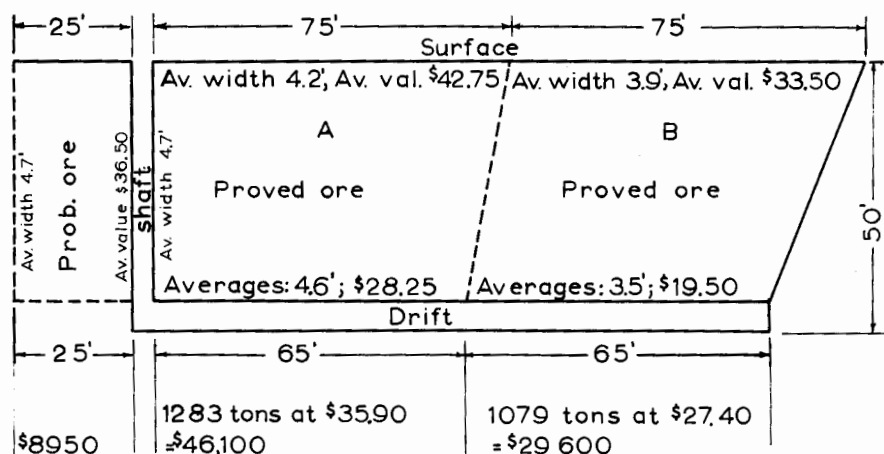


Fig. 10-8. - Section of Vein Showing Blocks of Ore

Block B is computed first:

$$\text{Volume} = (\text{average length } \frac{75' + 65'}{2} = 70') \times (\text{average width}) \times (\text{depth})$$

$$\text{or } 70 \times \frac{(3.9 + 3.5)}{2} \times (50) = 12950 \text{ cubic feet.}$$

In quartz veins containing few sulfides, accurate results are obtained if it is assumed that twelve cubic feet of vein material weighs one ton. (Metallic ores weigh from three to eight cubic feet per ton).

$$\text{Weight} = \frac{12950}{12} = 1079 \text{ tons}$$

The average value per ton of a block of ore is computed from the average value of the ore in the openings which bound the block. The vein, however, has a different average thickness in each of the openings therefore it is necessary to weight the values in each opening. This weighting is accomplished by multiplying the area of vein sampled in each opening by the average value found in that opening. The sum of the products (area) \times (value) is then divided by the sum of the areas to obtain the average value of the block:

$$(\text{Length}) \times (\text{width}) = (L \times W), \text{ which, times value,} = (L \times W \times V)$$

$$\text{Trench: } 75 \times 3.9 = 292 \times \$33.50 = 9800$$

$$\text{Drift } 65 \times 3.5 = 227 \times \$19.50 = 4440$$

$$\text{Sum} \quad \quad \quad 519 \quad \quad \quad 14240$$

$$\text{Average value block B } \frac{(L \times W \times V)}{(L \times W)} = \frac{14240}{519} = \$27.40$$

$$\text{Total value of block B} = (\text{tons}) \times (\text{Av. value}) = (1079) \times (27.40) = \$29,600$$

Block A is next computed:

$$\text{Volume} = (L \times W \times D) = \frac{(65 + 75)}{2} \times \frac{(4.2 + 4.6)}{2} \times (50) = 15400 \text{ cu. ft.}$$

$$\text{Weight} = \frac{15400}{12} = 1283 \text{ tons}$$

$$(\text{Length}) \times (\text{width}) = (L \times W) \times \text{value}, \quad (L \times W \times V)$$

$$\text{Trench: } (75) \times (4.2) = (315) \times (\$42.75) = 13470$$

$$\text{Drift: } (65) \times (4.6) = (299) \times (\$28.25) = 8450$$

$$\text{Shaft: } (50) \times (4.7) = (235) \times (\$36.50) = 8580$$

$$\text{Sum} \qquad \qquad \qquad 849 \qquad \qquad \qquad 30500$$

$$\text{Average value block A } \frac{(L \times W \times V)}{(L \times W)} = \frac{30500}{849} = \$35.90$$

$$\text{Total value block A} = (\text{tons}) \times (\text{Av. value}) = (1283) (\$35.90) = \$46,100$$

From blocks A and B, the total tonnage and value of proved ore are calculated.

$$\text{Total weight of proved ore } 1079 + 1283 = 2362 \text{ tons}$$

$$\text{Total value of proved ore } \$29,600 + \$46,100 = \$75,700$$

$$\text{Average value of proved ore } \frac{\$75,700}{2361} = \$32.00 \text{ per ton}$$

As the drift lies in ore, the next step would be to extend the drift on the other side of the shaft, blocking out more ore on that side. Before such work is done, however, it is reasonable to set a value on any ore that might lie on that side. It is opened only on one side and cannot be taken as proved more than a few feet. It is, however, probable ore for at least 25 feet. Practices differ as to setting a value on probable ore; here 50% of the computed value is used:

$$\text{Weight of probable ore} = \frac{(\text{length}) (\text{width}) (\text{depth})}{12} = \frac{(25) (4.7) (50)}{12} = 490 \text{ tons}$$

$$\text{Total value of probable ore} = \frac{(490) (36.50)}{2} = \$8950$$

$$\text{Total value of proved + probable ore} = \$84,650$$

There is, in addition, the prospective ore, which cannot be evaluated, but which certainly has a value. It is the prospective ore which lifts this example from the prospect class to the mine class, although only further development work can prove this. The present value of \$84,650 must cover the mining and milling of 2851 tons of ore as well as pay the cost of exploration to date. If careful arithmetic shows this to be possible, mining should begin, leaving it to the prospective ore to provide the profit. Of course, if the prospector wishes to sell his property at this stage, he will have difficulty finding a buyer if the value of only the proved ore is taken into consideration.

In addition to considering the habit of veins in the district when deciding how far proved and prospective ore should be extended from a sampled opening, all other geological evidence must be considered. Suppose that in the hypothetical mine just described, the shaft was sunk in the intersection of a shear zone with the vein, and the drift was driven in a zone of the vein where the wall rock is limestone, which in the district is favorable to ore deposition. Both exposures are in enriched portions of the vein, and the proved ore extends only a few feet beyond these sampled areas.

A mine usually produces less than the estimate indicates. How much less depends on how uniformly the ore is distributed and upon many other factors. Herbert Hoover cites examples where the recovery was consistently ten to twelve per cent lower than the estimated value. He attributes this to the inability to stope the mine to as fine limits as it can be sampled, with consequent dilution of the ore by waste, and to the friable character of the sulfides which tends to make them concentrate in the samples. This concentration produces a greater proportion of ore minerals in the sample than actually is the vein.

If the vein is narrower than can be stoped, say one foot wide, the value per ton must be reduced to take account of the barren rock which must be mined. This value is found by cutting the sample across the whole stope width, say two and a half or three feet, or by dividing the value per ton found across the vein by two and a half or three. Careful mining makes possible the separation of waste from ore fairly easy, so that the waste need not be milled, but still it must be mined, mucked, and trammed from the mine.

PROSPECTING AND EXPLORING LODGE DEPOSITS WITH BORE HOLES

The three kinds of drills which are likely to be used in prospecting for or exploring a lode are the churn drill, the diamond drill, and the ordinary pneumatic hammer drill. Of these the diamond drill is most used. Another core drill using chilled steel shot as the cutting medium

is little used in Alaska.

The prospector must understand the limitations and advantages of drills and ascertain upon what kind of deposits they can be used. The limitations and advantages can be summed up as follows: Drills, under the proper circumstances, make openings faster and cheaper than drifting, sinking, or raising, but they provide much smaller samples. There is probably no place in prospecting or exploration work where the larger opening made by drilling and blasting is not preferable to the small opening made by a drill, but a compromise must be struck between speed and lower cost on one hand and size of sample on the other. In Chapters 11 and 14 some of the techniques and practices of operating drills are described, but here only the applications are considered.

At this point it is instructive to discuss the influence of type of deposit upon choice of sampling method. Consider a deposit regular in shape and of perfectly regular grade. One drill hole anywhere indicates the grade, and a few around the edge indicate the size and shape. If the grade varies gradually and slightly, a few more holes are necessary. Where the grade varies markedly and the deposit is of irregular shape, many more drill holes are necessary to indicate the grade, and then this grade indication is only approximate. If the grade varies greatly and the values are not evenly distributed throughout the ore but are scattered, as Herbert Hoover has said, "like plums in a pudding," then the drill will not tell anything at all about the grade of the ore because the chance of hitting one of the "plums" with a small drill hole is very slight. Of course, if enough holes are drilled, an accurate estimate of ore reserves and grade can be made; but it may be necessary to practically mine out the whole deposit with the drill to attain this accuracy. In such deposits, the drill can only be used to determine the size and shape (on the basis of gangue minerals), leaving the determination of tenor to the sampling of larger openings. As an example, if the "plums" are three feet apart, a two inch hole has little chance of hitting one, and the only way to sample the deposit is to drill many holes or to drive larger openings. (This same principle is used in prospecting for even larger "plums," as in one project in Africa described by McKinstry. Traverse lines were laid out 2400 feet apart, on the theory that an ore body would have to be at least 1200 feet long to be economically interesting in that remote area, and that a 1200 foot orebody would betray its presence by float on at least one of the lines 2400 feet apart. Several areas were detected which were given more detailed attention).

Ordinarily the churn drill cuts a larger sample than the diamond drill or hammer drill but has two limitations: it only drills vertical holes, and it chops up the sample. It will drill into almost any type of material, although the hole must be cased if the ground is loose or wet. The samples are removed by a sludge pump or bailer and are caught in a long launder, called a dump box. Because it only drills vertically, obviously it has no application in exploring steeply dipping deposits such as veins or dikes. It is, however, useful for exploring flat lying beds or massive deposits. The churn drill is the only type used in prospecting placer deposits, and it is described in detail in Chapter 14.

The churn drill can only drill vertical holes, cannot be used underground, except in unusual circumstances, and chops up the sample. The drill most often used in hardrock prospecting is the diamond core drill. This drill has a hollow, rotating shaft, tipped by a cutting bit set with industrial diamonds. As the drill rotates and advances, a core is recovered in the hollow shaft, and sludge from the cut portion of the hole is also recovered. This method of drilling makes solid cores available for inspection and study. The diamond drill drills in any direction, but drills faster in some directions, as is discussed in Chapter 11.

Since it drills in any direction, the diamond drill is applicable to exploring steeply dipping veins. For example, suppose a vein outcrop has been discovered striking E-W and dipping south at 45° . The outcrop shows encouraging values, and enough trenching is done to show that it is continuous for at least several hundred feet horizontally. The vein is in fairly

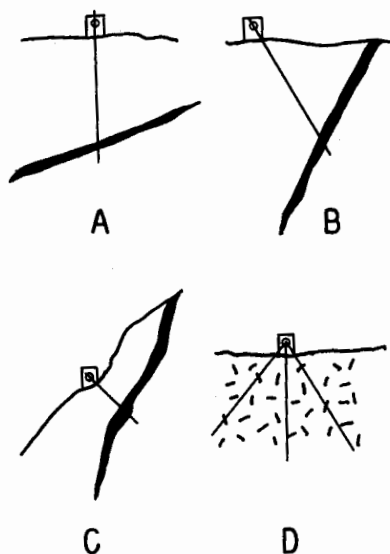


Fig. 10-9. - Possible Diamond Drill Holes

flat country so that not much about its vertical extent has been learned by trenching. In this case, an inclined shaft must be sunk right on the ore, but quicker and cheaper information on the vertical extent of the vein, information which might be wanted by a large company before it would begin expensive shaft sinking, can be obtained by diamond drilling.

Most diamond drill holes are drilled vertically downward rather than in an inclined direction. Exceptions to this rule might be justified where the vein dips steeply. (Fig. 10-9B) or on a hillside (Fig. 10-9C). Sometimes holes are fanned out from one setup (Fig. 10-9D) to save the cost of a new setup. This is particularly justified in massive deposits. A drill hole may also be angled in order that it cut across bedding at a right angle. Holes drilled through rock of varying hardness tend to curve, and by drilling at right angles to bedding, a straighter hole is possible. In deciding the direction and position of diamond drill holes, information to be gained must be balanced against cost. This requires judgment and compromise, the result of experience. It should be borne in mind that at this stage the chief interest likely is whether the vein is there rather than the assay value of the ore.

Another extensive use for the diamond drill is exploration from an underground setup. For finding a faulted section of vein or for finding parallel or en echelon veins, the diamond drill is invaluable.

The third type of drill used in lode prospecting or exploration is the pneumatic hammer drill such as is used for boring blast holes. Usually these drills are used for short exploratory holes underground, but holes have been drilled to over 200 feet using special couplings. Heavy rigidly mounted drills are used for the longer holes. The sample is, of course, cut to a sludge in the process. The best use for pneumatic drills probably is on short exploratory holes, using diamond drills for longer ones.

References

- Hoover, Herbert, 1909, *Principles of Mining*: McGraw-Hill Book Co., Inc., New York
McKinstry, Hugh E., 1948, *Mining Geology*: Prentice-Hall, Inc., New York
Peele, Robert, 1941, *Mining Engineers' Handbook*, 3rd Edition: John Wiley and Sons, Inc., New York, Section 10
Von Bernewitz, M. W., 1943, *Handbook for Prospectors and Operators of Small Mines*: McGraw-Hill Book Co., Inc., New York

Chapter 11

DIAMOND DRILLING

THE DIAMOND DRILL

Diamond core drilling in Alaska requires no such specialized techniques due to climate as does placer churn drilling, except in penetrating frozen overburden. The techniques and special problems encountered in diamond drilling are covered in several excellent publications (see references at end of chapter); consequently this chapter is much shorter and less detailed than is Chapter 14, which deals with placer drilling.

In diamond drilling, a hollow cylindrical bit, the cutting edge of which is set with industrial diamonds, is rotated on the end of a hollow shaft, known as the drill rod or drill rods. Next to the bit is the reamer shell, set with diamonds on its outer edge, which reams the hole to a standard diameter. Between the rods and the reamer shell is the core barrel, into which the core penetrates as it is cut. Core barrels are manufactured in lengths of two feet, five feet, and ten feet, but special lengths may be ordered. Inside the core barrel is the core lifter, core catcher, or core spring, which expands when the rods are raised, gripping the core so that it cannot drop back into the hole.

The rods are made in flush-jointed or coupled sections, from two feet to about fifty feet in length. They are rotated by a chuck in the drill head and are advanced by screw or hydraulic feed. Screw-fed drills usually have four speeds; hydraulic-fed drills have an infinite number of speeds within a certain range. Power is supplied by gasoline engine, or for underground work, electric or air motor.

Water is pumped through the drill rods, returning on the outside of the rods. This water cools the bit and washes cuttings from the hole. Water must be brought to the drill and stored in barrels or a sump, and forced into the hole by a pump, often an integral part of the drill. Thus, a primary source of water must be located, not too far away. Fig. 11-1 shows a special portable drill (the "Packsack") developed by the Acker Drill Co.

CASING THE DIAMOND DRILL HOLE

When drilling underground or in bare hard rock on the surface the prospector may drill an open hole right from the collar. Where overburden or soft crumbly rock exists, however, the first part of the hole must be cased.

For vertical holes or inclined holes this casing is driven somewhat as is churn drill casing (see Chapter 14). For this process, and also for pulling rods, some form of derrick is usually required. Few small diamond drills have derricks; usually a tripod is built at the drilling site.

When starting a hole on the surface, the prospector builds a stable level foundation of timbers and planks at the site, and sets the drill upon it. A slot or hole is left in the platform for the casing and rods to go through. A rack to keep extra rods off the ground is also built. If the drill has no derrick, a tripod with a crown sheave large enough to take one inch or one and one-eighth inch left-layed manila rope should be erected over the site. A starter hole is dug with a shovel or post hole digger, and the first joint of casing with drive shoe attached to the bottom is set in the hole. If the overburden is very thin, this joint may be driven to bedrock with a sledge striking against a special hand drive head screwed to the top of the casing.

Usually, however, the casing is driven by power. A drive head with a threaded hole in its center is screwed to the top of the casing. Into the threaded hole is screwed a drive head guide, and the drive weight is slid down the guide to the drive head. The drive weight is fastened by short lengths of chain to the rope, which goes through the crown sheave and back down to the ground. When driving, the driller takes two or three turns around a cat-head on the drill, and by alternately pulling and releasing the rope, lifts the weight and allows it to drop on the drive head. During the driving, a helper turns the casing with chain tongs or pipe wrench. When the casing can be driven no farther, the weight and drive cap are removed, and a wash tee screwed onto the top of the casing. A section of drill rod is fitted at the bottom with a chopping bit, either chisel or crossbit type. (A drill rod cut off at about 45° with a hacksaw makes a good chopping bit). The water swivel is fitted to the upper end of the rods and connected through a hose to the pump. The water swivel, as its name implies, can turn and still provide a water tight joint. Below the water swivel, the lifting bale is clamped to the rods, to which is fastened the rope. Sometimes instead of the water swivel, a tee, plugged at one end, is screwed to the top of the rods. The water hose is fastened



Fig. 11-1. - Portable Diamond Drill (the "Packsack") in Operation. This drill is smaller than the ones described in the text. Courtesy Acker Drill Co.

to the unplugged end of the tee, called the goose neck. A piece of chain is wrapped around the goose neck and fastened to the rope. The water is turned on and spudding with the rods started, with one man alternately tightening and releasing the rope on the cat head, and one man turning the tools (see Chapter 14). Cuttings are flushed upward and may be caught in a tub under the wash tee if desired (although usually not at this stage). The hole is drilled as far ahead of the casing as possible, the rods removed, and the casing driven. When bedrock is reached, the casing is driven into rock to form a watertight seal. Broken rocks near the surface should be cemented.

At shallow depths, especially when the casing is to be left in the ground to preserve the hole, the casing is pulled and ordinary pipe is substituted for it. Casing is pulled by substituting a pull piece for the drive head guide. The pull piece is similar to the guide, except that it has a heavy coupling at its upper end against which the drive weight can strike an upward blow. During the pulling, a safety clamp is kept around the casing to keep it from falling down the hole. Should the casing be stuck tight, making pulling difficult, jacks can be used, working against a pipe clamp (see Chapter 14).

Even where the hole is started in rock or stiff clay, a short length of pipe, the stand pipe, should be driven a short distance into the ground. This pipe projects above the surface, keeping objects from falling into the hole, and, through the wash tee, providing a return path for water with suspended drill cuttings.

If the hole is being started at some angle other than vertical, the direction is accurately laid out with a compass or transit, and the inclination laid out with a clinometer or Brunton compass. The casing is started by hand, and if necessary to use the drive weight, an auxiliary guide is built, to keep the casing with the drive block and drive block guide pointed in the right direction until the casing is deep enough to maintain its direction.

The same rules apply to driving and pulling casing which apply to churn drilling in thawed ground. (See portion of Chapter 14 dealing with thawed ground). In driving casing for diamond drilling, however, it is not necessary to keep a plug in the casing as it is when drilling for placer. It is necessary, however, to keep an accurate account of the length of casing and of drill rod in the ground, so that it is known when the drill bit is ahead of the casing. When casing is to be used, a larger hole is drilled ahead; a Bx bit makes a hole large enough for an Ax casing.

CORE DRILLING

When the hole has been cased to bedrock and sealed off, core drilling in hard rock begins. The chopping bit is removed from the rods; and the core barrel, reaming shell, and diamond bit are attached. Pipe wrenches can be used for assembling, but care must be taken not to grip the diamond areas with the wrench. Double tube core barrels, which are thin walled, give better core recovery, but these should be gripped with palmalee wrenches which will not crumple the sides. When screwing together joints of rods, the driller should wrap the joints with cotton wicking, or insert a copper washer between rods to facilitate uncoupling later and to make a watertight seal. The threads of the rods must be perfectly clean.

The bit is lowered slowly into the hole, with lengths of rod added as needed, until the bit is on the bottom. A safety clamp or lowering iron is used to hold rods while screwing on new lengths. The water swivel is then attached to a feed drill rod, which is then inserted through the spindle of the drill head. The drill is moved forward until the head is over the hole, and the feed drill rod is connected to the rods projecting from the hole. The water is turned on and the hole flushed to clean the bottom, at which time the rods will settle several inches. The rods are turned with a wrench to make sure they are free, and the chuck jaws tightened. The rods are carefully centered, and one jaw marked with crayon. This jaw is not disturbed when removing rods so that when the chuck is retightened, the rods will be centered.

Rods or casing must be handled carefully to protect the threads; diamond bits and reaming shells must be treated as diamonds rather than tools. The diamonds are very hard, but brittle and easily pulled from their matrix if the bit is allowed to turn on loose or crumbly rock. If run dry or at an excessive rate of speed, the matrix will fuse, and some of the diamonds be lost or the bit burned into the rock and stuck.

The drill is started and run slowly, with plenty of water to wash away the cuttings. Because bedrock is likely to be more fractured and seamed at the surface than farther down, great care must be taken at first. It is axiomatic with drillers that "more damage is done to the bit in the first five feet than in the next hundred". At this beginning stage, if the rock is not too hard, a steel sawtooth bit or a carbide insert bit may be used to save wear on the diamond bit.

The drilling speed when the bit encounters solid rock may be increased. The actual rotational speed of course, depends on many factors, chiefly rock type, core recovery, and bit wear, and can only be determined through experience.

The rate of feed depends upon the same factors as does rotational speed. Both, of course, are made as great as possible without sacrificing good core recovery and low bit wear.

The rate of water flow should be just enough to carry the cuttings out the wash tee. The use of too much water increases the velocity of the sludge-laden water and results in excessive bit erosion. In soft rock, the water flow should be increased to handle the larger particles that result. The returning water is one of the driller's greatest aids. By catching sludge in his hand he can tell what kind of rock he is drilling, and whether the rock is breaking or being cut. If water is being lost, he knows he is in seamy rock. If the pressure rises, sometimes opening the relief valve, he knows the bit is plugged, and that a piece of rock has become wedged in the core barrel, preventing the core from entering. Procedures for dealing with plugged bits vary. The bit may be backed off, allowing the hole to wash for a few minutes. The drill may be allowed to advance in an attempt to force the restriction into the barrel. If these attempts fail, the rods must be pulled and the bit cleaned.

When drilling through solid hard rock, the driller encounters little difficulty; it is in fractured rock that trouble occurs. Unfortunately, places having these conditions are places mineralization is likely to occur; and, consequently, places where core and sludge recovery are most important. One of the most effective ways of getting through a sheared zone is to substitute a solid carbide tipped bit or to chop through. No core is recovered; the sludge, though, will give much information on material and values. The trouble with this procedure is that the water, with the sludge, is apt to be lost in seams in the shear zone and create what is known as a blind hole. Sometimes the hole will seal itself with cuttings, but usually it is necessary to grout the hole from the outside. Sawdust, bran, oats, drilling mud, or quick setting cement pumped down the hole may plug the leaks. If these materials fail, quick setting cement is pump-

ed down the rods or lowered in a bailer. After it sets, the plug is drilled through, and the process repeated. In shattered ground, a double tube core barrel, more effective in recovering core is used (it may be used in any type of ground, but is more expensive than the single tube barrel).

The driller must be able to visualize conditions in the hole from the operation of the equipment. Vibration or chattering usually means broken ground; the drilling speed should be reduced until it is decided what action to take. In hard rock, for good recovery, the drill should run at low speed and heavy pressure; in soft rocks at high speed and low pressure.

By keeping an accurate record of the advance, the driller knows when the core barrel is full or should be full (100% recovery is seldom attained). After advancing a distance equal to the length of the core barrel, or until the barrel is plugged, the drill is then stopped and the hole is washed until the return water is clear (assuming the water is not being lost before it returns). This washing is essential as the water column in the hole is loaded with sediment in suspension which would settle and pack around the bit if the pump were stopped with the rods in the hole.

The safety clamp or dog is engaged and the rods are unscrewed at the first joint. The hoisting swivel is screwed to the top, and the rods are raised by power. Each successive piece of rod is removed with care as any sudden jerk or jar might dislodge the core. When the core barrel is on the top, the bit is removed, and the head end of the barrel is tipped up to allow the core to slide out. The core is laid out just as it comes from the hole, with an attempt made to leave blank spaces where no core was recovered (this information must come from the drill log). A special core box, used to store cores, consists of several compartments running the length of the box, each of which takes a length of core.

The drill log usually is kept in a notebook, from which it is transferred to a permanent log of the drill hole.

When the core barrel is emptied, the bit, reamer, and barrel are reassembled and the rods are inserted in the hole again. If a stub of core is left in the hole, the rods should be turned by hand to seat the bit over the plug. If the plug is broken off and loose, and if it is small, it may be ground out with the diamond bit. (This grinding is hard on bits). If the loose plug is large, it may have to be chopped up with the chopping bit.

Sometimes core recovery is unimportant, as in the early stages of a hole. In this case it saves much time if a non-coring or plug bit can be used to grind up the material. Either carbide tipped, fishtail, or diamond bits may be used, the first two in overburden or soft rock. Experience has shown that in the smaller sizes, Ex and Ax, the plug bit is faster than the coring bit in the Bx size; the two are about equally fast, and in the Nx size, coring is faster.

The two most expensive items in diamond drilling are the labor and the diamonds. The driller must know when a bit is ready for reconditioning. Even if a bit is not abused, the metal of the matrix finally wears enough to allow a diamond to fall out. Two or three loose diamonds riding in the bottom of the hole can quickly ruin a bit. The driller must take his bit out of service before this happens. By so doing he also maintains the gauge of the hole and saves wear on the reaming shell.

Sludge may be recovered by running the water into a tub and allowing it to overflow. The fines and light material will overflow and be lost, so the sample is not representative. Better results are obtained by using a sludge box, an elongated metal box with one or two transverse baffles to allow much of the fine material to settle as the water passes the length of the box and overflows. The most reliable method of sludge recovery is to swing a pipe or launder from barrel to barrel, catching all the water and holding it until all sediment has settled. The sludge from each run is kept separate and labeled to correspond to the core from the same run. Sludge is dried over slow heat in pans, sacked, labeled, and stored.

Nevertheless, due to a number of factors, the sludge sample may be misleading. Some water may be lost in seams, and with it, some sludge. Abrasion of the rods or simple slaughting may cause material from above to salt or dilute the sample. The diameter of the hole may be greater in soft rock than in hard rock. A worn bit may be cutting a smaller hole than standard.

Sludge and cores are saved for assaying. Cores are examined and a description of them recorded. Before being assayed, they are split lengthwise with a special core splitter, and one half is retained for a permanent record. Sometimes the cores are photographed before splitting.

Drilling from an underground setup presents some problems not encountered on the surface. When drilling straight ahead into the face of a drift, the driller usually has plenty of room for pulling the rods. When drilling off to the side or up or down however, he may find it necessary to blast out a station to make room. Even so, it is usual to use shorter rods than are used in surface drilling. When drilling horizontal holes from an underground setup, it is good practice to angle the hole slightly upward. The angle makes pulling the rods much less work, and the job of removing loose plugs or diamonds from the bottom of the hole much easier. In up or down holes an air cylinder is used to push and pull the rods.

Another problem often encountered underground is the flow of water from a hole that cuts a shear zone. Usually the flow of water slows down after a few hours, but if water must be pumped from the mine, there may be no time to wait for the water to slow. For moderate flows a cedar pole may be hewed and driven into the hole where it will swell and seal itself. For stronger flows it may be necessary to drill a hole in a cedar plug, and to insert a pipe with an open valve

attached. The valve is shut after the plug swells.

Several accidents may occur which require fishing for lost parts. Lost diamonds are recovered by sending down an old bit filled with wax, or if the hole is not clean, they may be picked up with a bailer (see Chapter 14). Unscrewed rods are picked up by simply screwing them on again. If the rods are lost in a fault or oversized hole, sometimes it is necessary to use a bent rod in order to engage the threads. Broken rods are caught with a recovery tap, which goes over the end of the rods and engages them with threads. Jammed or buried rods may have to be jacked out.

Drill equipment is manufactured in the following standard dimensions.

Symbol				Casing		Approximate Diameter	
Casing, Coupling, Bits	Rod and Rod Coupling	Bit diam. inches	Drill Rod Outside	Outside Diam.	Inside Diam.	Hole*	Core
XRT (Designation to cover any special size)							
EX	E	1 7/8	1 5/16	1 13/16	1 1/2	1 1/2	7/8
AX	A	1 27/32	1 5/8	2 1/4	1 19/32	1 7/8	1 3/16
BX	B	2 5/16	1 29/32	2 7/8	2 3/8	2 3/8	1 5/8
NX	N	2 15/16	2 3/8	3 1/2	3	3	2 1/8

*Slightly larger than bit diameter

The approximate amounts of water needed to maintain a rising velocity of 1.5 feet per second, (sufficient to raise everything but heavy metallics) are as follows:

Casing	Rod	Gallons per hour
XRT		
EX	E	120
AX	A	192
BX	B	432
NX	N	732

Drill logs may be kept in many forms. The following is modified from that recommended by the Acker Drill Company, Scranton, Pennsylvania.

Record of bore Hole No. _____							
For _____				Location _____			
Started _____		Finished _____		Diam. _____			
Drill runner _____				Helpers _____			
STRATA	PIPE		ROCK		TOTAL DEPTH		REMARKS
	Feet	Inches	Feet	Inches	Feet	Inches	
Broken B. C. Schist	3	8	2	6	6	2	
Broken B. C. Schist			6	0	12	2	Top solid B. R.
Solid B. C. Schist			8	2	20	4	
Vuggy Sheared Quartz			2	5	22	9	Much water
Vuggy Sheared Quartz			2	0	24	9	Much water
B. C. Schist			2	6	27	3	Much water

In addition to the log, a sketch of the hole should be made as the work progresses.

References

- Acker Drill Co., Inc., 1956, Basic Procedures of Diamond and Shot Core Drilling
Cumming, J. D., 1951, Diamond Drill Handbook: J. K. Smit and Sons of Canada Ltd., Toronto
Forrester, James Donald, 1946, Field and Mining Geology: John Wiley and Sons, Inc., New York, p. 398
Peele, Robert, 1941, Mining Engineers' Handbook, 3rd Ed.: John Wiley and Sons, Inc., New York

Chapter 12

PROSPECTING AND EXPLORATION OF PLACER DEPOSITS

GENERAL

Chapter 9 discussed the preliminary work of acquiring knowledge of the country by reading and conversing with other men, and the reconnaissance of the area. Chapter 10, assuming that indications of the existence of a lode deposit were discovered, discussed the methods used in locating and exploring a lode deposit to the point where it can be decided whether to drop the work or begin developing mine.

This chapter assumes that enough evidence has been uncovered to justify prospecting for, and exploring of a placer deposit. At this time, when the prospector is trying to decide whether to begin digging to try to outline a placer (or a lode for that matter), he must sit down and state his justifications, and it might be well to check them off against the conditions quoted in Chapter 10 from Peele, which may be expanded as follows:

General circumstances which are favorable to either lode or placer deposits.

1. Presence of ore outcrops, or presence of working mines in the vicinity.
2. Presence of float as chunks of ore, specks of metal, or in tiny amounts as determined by geochemical analyses.
3. Favorable geological conditions.
 - a. Presence of igneous intrusives. See Chapter on mineral deposits for what minerals to expect with certain types of rocks.
 - b. Country rock sufficiently old to enclose deposits formed during metallogenetic epochs.
 - c. Other evidence of mineralization, such as mineral springs, incrustations, oxidation products and mineral stains, cellular structures, alteration zones, or shear zones.
4. Ancient workings (unimportant in Alaska).

Before undertaking detailed prospecting for a placer deposit, the prospector should observe a few more conditions.

1. Float (ore or specks of metal) should be found in the basin of the creek to be prospected, or prospects should have been found in a creek draining the same region.
2. The creek should not have been glaciated during the late Pleistocene time. (See discussion of effects of glaciation on placers in Chapter 6). Still, there is a fairly good chance that even in the glaciated regions of Alaska, at least north of the crest of the Alaska Range, mineralized regions containing lode gold may contain one or more placer creeks.

It is assumed that the prospector has decided upon a specific creek because it drains a mineralized area, or specks of gold have been found in its basin, or because good prospects have been found on adjacent creeks. The creek has already been traversed on foot, and no bedrock has been found. The following questions should be answered: Is the creek running on muck or on gravel? If on gravel is there muck above on the benches, and if so, how deep is it? What is the grade of the creek, and how much water is flowing? Is bedrock exposed on a rim (sloping bedrock wall of a valley)? If in glaciated country, are there any moraines and what is their distribution? Are any boulders showing? How long is the creek? If a placer is found, how will it be worked? (This last depends upon the depth, grade, water, etc.). As a guess, how deep is bedrock?

A creek prospected for placer must be crosscut from rim to rim, or toward each limit until bedrock is so shallow that there is no possibility of a placer existing. Crosscutting means taking a sample at such intervals that a paystreak will not be overlooked; on some creeks where the metal is well distributed and spread out, this sampling may be accomplished by drilling a hole every 100 feet across the valley. On others, where the gold occurs in a narrow streak and consists of widely scattered large nuggets, it may be necessary to actually drift across "from rim to rim". Another type of creek even more difficult to prospect is like Hommond River in the Koyukuk district, in which a paystreak of coarse nuggets was formed in a deep channel through which the water rushed with great force. On this type of creek the gold was washed for several tens, and in places hundreds of feet between crevices in bedrock, and is found only in the crevices. If such a channel is crosscut between crevices, no gold will be found. Here it is necessary to drift up and down the creek for a considerable distance before giving up. Fortunately, such channels are usually narrow.

OPENCUTTING

If the creek is fairly narrow and does not appear to be too deep, there may be a zone near its head where bedrock can be reached with a small opencut. This process, which was described in Chapter 9 as "running a drain," must be continued to bedrock. If a bulldozer is available, the opencutting is done rapidly in shallow ground. If equipment is not available, however, the drain must be run by ground sluicing. If the creek is expected to be deeper than ten or twelve feet, it is best to sink holes first, because, to reach the same depth, a great deal more material must be removed from an open cut than from a shaft. However, the open cut will almost always provide more information than a single shaft.

The cut is started directly over what is thought to be the channel. If the creek is narrow, the location is no problem; if wider, one place is as good as another, and the creek bed, being the lowest, is usually chosen. Brush and mass are chopped out for a width of about eight to ten feet and thrown on the side unless the current is fast enough to carry it completely away. If the debris catches in the drain, it may later hinder the flow of material suspended in the water. The moss should be saved for use later in building walls, dams, or in setting boxes.

The brush is stripped off as far upstream as it is expected the cut will be carried, which in turn depends upon the depth and the grade at which the drain can be kept open. If the grade is five percent and the drain will keep itself open at two percent, the drain will be deepened three feet for every hundred feet advanced upstream. Therefore, if bedrock is fifteen feet deep, the drain must be five hundred feet long.

Small rocks are thrown or wheeled out of the cut, and the larger ones are piled into dry-walls along the sides. For this work a pick, shovel, and prybar are used; and if one is available, a multi-tined sluicefork with which small rocks can be thrown out without removing gravel. Hip length rubber boots are worn. (A rubber apron made from an old boot is helpful when wet rocks are being carried). Boulders too large to carry are rolled to the side of the cut; blasting may be necessary. During the spring runoff, or spring water, most of the material of the cut is removed. The size (volume) of the pieces which a stream can move increases as the sixth power of the velocity of the water, and a stream at flood stage will sweep out of the drain gravel and cobbles which in ordinary stages would have to be thrown out. The shovel can be used to help along gravel in slack water.

High water may be a hindrance as well as a help if it cannot be controlled. The ground-sluicer, or any opencut miner, who does not make provision for conducting high water around his cut is at the mercy of high water. A stream adjusts its gradient until it can barely transport its load. If the prospector lessens the gradient of that portion of the stream flowing through his cut by three or four percent, obviously it will not be steep enough to carry materials coming down the creek in high water. The stream then will drop part of its load in the cut until the natural gradient is restored.

Before the cut is too far along, therefore, a way must be devised to control the water, usually with a dam which can spill to a waste ditch around the cut. If the amount of water which must be wasted is not too great, it may be deflected by a wing dam and led down one side of the cut; but a dam may be needed anyway to store water for use in dry periods. In starting the dam, the prospector cleans the vegetation away from an area a short distance above what will be the head of the cut and ground sluices all loose material. (It is important that the dam rest on tight material). To obtain more storage, a larger and deeper area is sluiced out. A small dam, where timber is available, can be built by laying a log across the creek at the lower end of the reservoir; and placing poles on the upstream side so that they lean against the log with their lower ends firmly imbedded in the creek bottom. The poles are leaned upstream and driven into the ground, moss and dirt are then built up to stop the water. If a heavier dam is required, log cribs are built and filled with rocks and dirt.

If poles are not available, a small dam can be built of flat rocks with moss between them. Silt in the reservoir tends to seal any leaks. Dams may also be built of brush and dirt, beaver fashion. A mouth piece, fitted with a gate, is built of lumber and inserted near the bottom of the dam. The spillway leading to the waste ditch is usually at a higher level than the mouth-piece, and is fitted with removable boards so that the depth of water which must be built up before the water overflows can be varied. Spillways and mouthpieces must be weighted down with rocks. An automatic gate on a log dam is shown in Fig. 12-1.

If the ground is so shallow that bedrock can be reached and sampled before high water can damage the cut, or if the cut is small and shallow enough so that such damage can be repaired easily, the prospector may not need a dam. Often he can find a place upstream where the water may be turned from the channel so that the flow is regulated at least partially.

As the water runs over the ground from which the vegetation has been stripped, the whole length is gradually deepened. The cut is widened by directing water against the sides with shear boards, so that the banks are undercut. Ground sluicing is also used in small scale mining. In prospecting, a narrow cut is usually all that is desired; in mining, the cut is as wide as the paystreak.

Only thawed material is removed, but in warm weather frozen ground usually thaws rapidly so that the water can work to capacity. Water is a better heat conductor than air, and

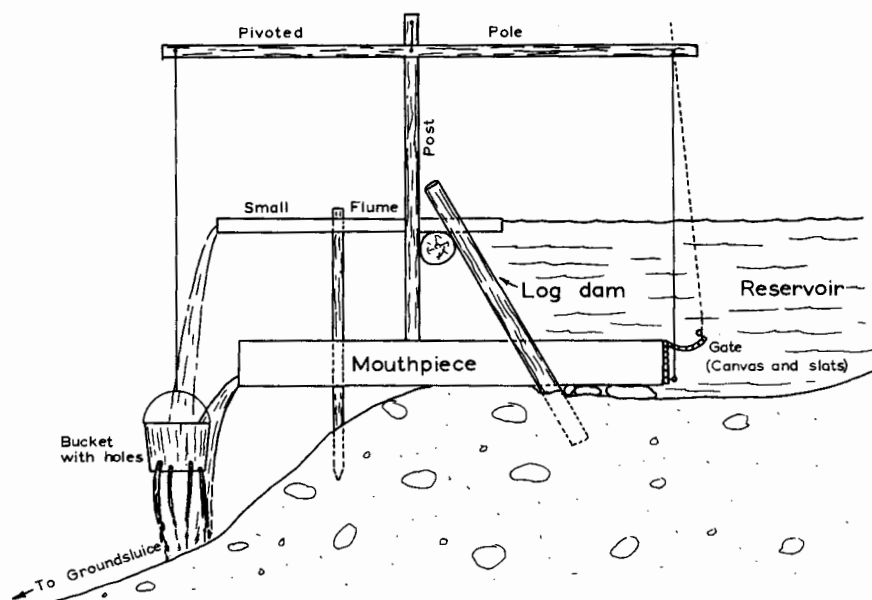


Fig. 12-1. - Cross Section of a Log Dam Fitted with an Automatic Gate. When Reservoir Fills, Water Flows Out Small Flume at Top and Fills Bucket. Weight of Bucket Then Lifts Gate, and Dam Empties. As Long as Water Continued to Flow, Gate Stays Open. When Reservoir is Empty Gate Closes and Reservoir Begins to Fill Again. Gate is Made of Heavy Canvas Nailed to Closely Spaced Slats. Bucket has Holes so that it Will Empty When Flow Stops. It May be Necessary to Adjust Weight of Bucket with Rocks.

relatively warm water thaws the ground effectively.

As the spring water from the melting snows disappears and rains do not swell the streams, the flow of water may become so small that only small pebbles and sand are removed, leaving all the larger material to be thrown out by hand. The eroding power of the water can be increased by splashing or booming with a dam; that is, the dam is allowed to fill up, and all the stored water is sent rushing through the cut in a splash, to sweep away the fines. In this way a large volume of water at a high velocity can be utilized. The dam is shut, and while it is filling, the rocks and boulders are thrown out, or stacked on the sides preparatory to the next splash; for if the larger material is not removed between splashes, it protects the gravel below from being washed away. The dam may be opened and shut manually or automatically. If manually, a long rope or wire reaching from the cut to the gate may be pulled to open the gate, which shuts itself after the water level drops. Usually, however, for a small cut, a simple board cover, fitted with a handle, is removed by the prospector and replaced after the water drops. Covers may be covered with cloth or canvas to make them fit tighter; the water pressure holds them against the upper part of the mouthpiece. The water rushing from the dam is conducted by flumes to where it is to do its work; otherwise it loses velocity. The additional danger of undermining the dam at its lower side can be obviated by laying sheet iron or flat rocks below the dam spillway.

After bedrock is reached by the drain, the cut is extended up the creek at bedrock grade, which is steeper than the grade of the drain. Because of this increased grade, larger material can be moved by the water in the cut than in the drain. Water flowing in a flume carries larger material than will the same amount of water flowing in an open cut. For this reason many prospectors or small miners extend sluiceboxes, without riffles, through the drain. Lacking this, it may be necessary occasionally to throw out the larger pieces which accumulate near the head of the drain.

To install the flume in the drain, a mouthpiece with wings is set on bedrock at the upper end of the drain. Moss is packed between the mouthpiece and bedrock to seal off any leaks, and is also packed around the wings, which are braced by poles extending downstream. (Moss may be conveniently carried on a sluicefork, over the shoulder). The sluice boxes are attached to the mouthpiece and extended down the drain. Because the drain has a flat gradient, it is doubtful if the flume can be run at any flatter grade than the drain. However, when such a string of boxes is installed in an old open cut which has been mined and which has as steep a grade as the creek, an attempt is made to set the boxes at a flatter grade than the bedrock grade of the old cut. This technique enables the lower box to be set some distance above the bottom of the cut, providing more room for tailing. Riffles may be placed in the first one or two boxes to catch any gold which might come down.

If the drain strikes bedrock in the channel or lowest part of the creek, it is likely that the information sought will be obtained, for if there is gold in the creek there should be some in the channel. To gain information on the sides, the prospector may widen the cut by deflecting the water as already described.

If, however, the cut reaches bedrock on one rim or the other, it is necessary to extend the cut upstream obliquely so that the creek is crosscut at an angle to the length of the valley. Here a flat gradient must be maintained; consequently no larger material will be moved through the cut than will go down the drain. The cut is extended until the channel is reached.

As mentioned earlier in this discussion, this method of prospecting a new creek, where nothing is known of the gold content, is attempted only when there is reason to believe that bedrock lies at a shallow depth; even in shallow ground, the prospector may be several weeks putting in his cut.

As the cut is deepened, the prospector continually digs down and pans what he digs. When he finds bedrock with his shovel, and if there is any gold showing up, he may want to mine a cut to determine the tenor of the ground. An area is ground sluiced to bedrock or to within a couple of feet of bedrock. The length of the cut depends on how much water is available and how many sluice boxes can be used. The sluice boxes are laid on the bedrock or on the gravel at a grade of at least six inches to the box length of twelve feet (4.16%). If the bedrock grade of the cut is greater than six inches to twelve feet, the boxes are set at a steeper grade, or the lower end of the sluice is elevated. If, as usually happens, the grade is less, the upper end of the sluice is raised on rocks or posts to attain more grade. It may be that to attain dump room for tailing at the lower end, and at the same time maintain sufficient grade, a considerable lift is necessary to throw dirt into the upper boxes. If the upper boxes are too high to be reached conveniently, a platform is built onto which the dirt is shoveled, and from which it is thrown into the boxes. When the lift is high, or the dirt is thrown a great distance horizontally, backboards are placed on the opposite side of the boxes from where the shoveler is standing to keep dirt from flying over. Another aid sometimes used is a wide board hinged on the side of the boxes. When the water is so low that sluicing must be done during splashes, the dirt is shoveled onto the board while the dam fills; during the splash the board is tilted up to dump the dirt while water is available.

Water is led into the boxes through a mouthpiece set on bedrock in the creek, or through a wooden flume or a flume hose, a large canvas tube which acts as a pipe when full. This hose is light and convenient, but rats after a few months' use. During the shoveling in process, all of the water must go through the boxes, or a good waste ditch must be provided to handle excess water, as the cut must be kept dry during the mining.

After ground sluicing and before setting the boxes, the gold originally contained in the whole thickness of gravel is concentrated on bedrock or in a thin layer of gravel on bedrock.

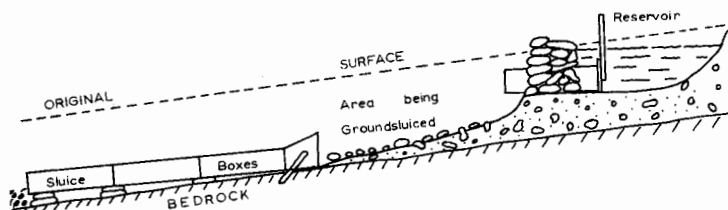


Fig. 12-2. - Longitudinal Section Along Creek Being Groundsluiced. Sluiceboxes are Set at a Flatter Gradient than that of Bedrock in Order to Obtain Tailing Room. Rocks Which Accumulate in Groundsluice are Piled Against Walls of Cut or Stacked on Ground Beside Cut. If Gold can be Sluiced into Boxes, no Further Boxes are Set. If Gold Cannot be Sluiced into Boxes, Boxes are Continued Through Cut, and Last Bit of Gravel Shoveled-in.

This gravel is shovelled in, and if necessary, bedrock is picked and shoveled in, until it is clean of gold. If the gold collects in crevices, it must be dug out with special small tools. Posts or flat rock piers are placed under the boxes if they are undermined by shoveling. If a cut is being shoveled in during the fall, thawed ground may be kept from freezing while standing overnight by picking loose dirt onto it before quitting time. If bedrock is smooth and hard, so that the gold does not work down, it may not be necessary to shovel in. The gravel is then all swept into the boxes set in a drain. Water under pressure from a hose from the dam is used for cleaning bedrock. Crevices must be cleaned out by hand. Fig. 12-2 shows a longitudinal section of a ground sluice.

The cut is made only as wide as dirt can be shoveled in conveniently, six to ten feet on either side of the boxes. If the paystreak is wider, the shoveling in is done in two stages (two cuts wide); the sluice boxes are moved over after the first side is shoveled in. Miners usually refer to the value of the ground worked in this way as so much to the box length of twelve feet. This method of evaluating ground is inexact because the width of the cut is not standard. Often a cut twelve feet wide is implied, which makes a "boxlength" 144 square feet in area. Fig. 12-3 shows a small groundsluicing operation.

When water is used to crosscut a bench, groundsluicing is done at right angles to the creek. In order for this process to be practical, bedrock on the bench must be higher than the creek level, so that drainage is available. Before attempting to crosscut a bench with water (which entails considerable labor or expense in ditch digging) the prospector should determine the bedrock elevations by sinking shafts. Sometimes after groundsluicing a drain in the creek bottom, it is found that bedrock slopes up sharply on a rim on one side or the other of the cut to a bench wide enough to contain a paystreak. If the bedrock in the bench channel does not lie at too low an elevation (there is no high bedrock ridge between the creek and the bench channel), and the bench is not too deep, groundsluicing may be practical. A ditch is dug to tap the creek far enough upstream so that water can be delivered to a point well up on the bench, and this water is allowed to run straight down the bench toward the bottom of the valley. If little water is available during the dry season, a small reservoir is dug at the end of the ditch. If a bedrock ridge lies between a bench channel and the creek, it may have to be blasted out to get drainage.

Water supply is very important when groundsluicing. In general, south of the Alaska Range water is no serious problem, as precipitation in most places is ample. In the Interior and on Seward Peninsula, however, lack of water is a deterrent to placer mining. Groundsluicing must be started early enough to take full advantage of meltwater in the spring, for by sometime in July in many parts of the country the water is greatly reduced in quantity. Deep snowbanks within the creek basin are very desirable for storing water, as are built-up icings or "aufeis." It is possible at times to augment the supply of snow which accumulates naturally by setting snow fences at right angles to the prevailing wind. The fence is left until the snow has built up to its top, then dug out and erected on top of the snow; this process is repeated all winter. Wimmeler cites an example where for a labor cost of \$1500 (during the 1920's) and with two parallel fences one mile long and five feet high, a snowbank forty or fifty feet deep was built up, which made the water last five weeks longer than usual the next summer. Snow of such depth thaws slowly.

CROSSCUTTING THE CREEK

If an open cut has shown the presence of gold near the upper reaches of the creek, or if it failed to reach bedrock, but the prospector still wants to prospect the creek (because of other justifying evidence), it may be necessary to crosscut the creek with drill holes or shafts. If possible, a place is chosen a short way down the creek where the channel is fairly well confined and where bedrock is exposed on one or both rims. These rims define the limits beyond which no placer can exist; and although it may not be necessary to work right up to them, at least the prospector knows the limits beyond which he need not go. Failing to find a place where bedrock is showing on the rims, the prospector chooses a place where appearances would lead to the belief that the channel is confined between rims hidden under sliderock. When saying that exposed bedrock rims set limits to where a placer can exist, it is assumed that the valley sides continue to rise above the rims. If a sloping bench exists beyond the rim, it should be investigated for a channel.

The creek can be crosscut with shafts or with drill holes. It is difficult to generalize in deciding which to use; the decision must be made after the circumstances are known. Some of the factors which may affect such a decision are listed below:

Drill Favored

Thawed ground
Uniformly distributed gold
Labor costs high compared to transportation and materials cost.
Area close to transportation

Shafts Favored

Coarse gold; nuggets
Labor costs low compared to transportation and materials cost.
Remote area



Fig. 12-3. - Groundsluicing Dam is at Upper End of Cut Outside of Picture. Rocks are Thrown and Wheeled From Cut Between Splashes.

The first item in favor of the drill, thawed ground, needs clarification. It is easier and yields more accurate results to drill frozen ground than thawed ground, and it is easier and yields more accurate results to sink a shaft in frozen ground than in thawed ground; but it is much more difficult to sink in thawed ground than to drill in thawed ground.

The second item, uniformly distributed gold, has already been discussed under sampling (Chapter 10). Uniformly distributed minerals can be sampled with fewer openings than can those distributed nonuniformly. If the gold is in the form of very coarse, scattered nuggets, it is even possible that the creek will have to be prospected by drifts running across and up and down from the bottom of the shaft.

The factor of relative costs is considered here as in all mining or construction work. When labor is expensive, more use is made of labor saving devices. However, where the cost of transporting heavy equipment to remote areas becomes an appreciable part of the cost, the use of more labor is advisable. Shafts are usually sunk when prospecting for a placer in a new area, and drills are brought in to explore the creek after gold is found. The drill is favored more as transportation methods improve. When everything was hauled by poing boat and dogsled, it was very difficult and expensive to move drills; but the airplane and the tractor have, in many instances, made it cheaper to haul a drill than to hire men for sinking shafts.

It is assumed that at least for a start, shafts will be sunk. The place is picked for the crosscut and the equipment hauled to the site. The prospector wants the first hole to strike the paystreak. He considers all the evidence, and decides (or guesses) where the channel will be—whether on the bench or in the creek, and starts his hole. If possible, a magnetometric survey, as is described in Chapter 15, should be made first. (Such a survey may take some of the guesswork out of selecting a site). At the start, the holes are sunk on hundred foot intervals because, although this spacing may be too great to find same paystreaks, it may be close enough for others. If it is too great, intermediate holes can be sunk where conditions justify. If the paystreak is known to be narrow, the holes are spaced at fifty foot intervals, or even closer together.

After a hole has been sunk to bedrock, the next one is sunk on the side toward which bedrock is dipping. The dip of the top of bedrock is known from actually measuring the slope of the bedrock surface, or by computing the elevation of bedrock in adjacent holes. If a paystreak is crosscut and delimited and a wide bench still remains unprospected, it is a good policy to finish the crosscut, for there may be another channel containing a paystreak. This work should be delayed until later, however, for the first rule of prospecting is to stay with the pay. If pay is found, the prospector should outline enough so that he can start mining or interest capital in his creek, to relieve himself of the economic stress which quite likely is besetting him after spending a season or more prospecting. To illustrate the conditions which may be encountered, several possible creek sections are shown (Fig. 7-4) based on known conditions on actual creeks. These several examples show how different underground conditions may be, even though the surfaces look somewhat alike. They also show the difficulty in deciding how to prospect a creek before anything is known of it. The only general rule is "crosscut the creek," although if the prospector finds nothing in the deepest channel in the creek, it is unlikely that he will find anything on the benches.

Finding pay in one crosscut or line of holes does not prove the existence of a block of ground; consequently the next step is to move up or down the creek and start a new crosscut. This line also should be started with the intention of hitting the paystreak with the first hole, and here there is more to guide the placing of the first hole. Even so, it is unusual to accomplish this objective. On the second line, if it is close to the first, it is unnecessary to crosscut the creek from rim to rim. The distribution of pay on the creek is determined by the first crosscut and guides the spacing of the holes in the next line. To continue sinking holes toward the limits of the second line, when it is known that a short distance up or downstream there is no pay on the limits, is a waste of time.

When first prospecting a creek, it is wise to leave long intervals, one fourth to one half mile between lines for the same reason that it is wise to leave big intervals between the holes. If the deposit is fairly uniform, this procedure will show its existence and outline it with a minimum of holes. If more information is needed, lines of holes can be sunk between the initial lines.

Leaving long intervals between the first lines, the prospector may find it necessary to crosscut the creek with each line rather than to depend on information from one line applying to the next. Channels have been known to split and come together again; extending the lines to completely crosscut the creek avoids missing any bench deposits. It is sometimes standard practice in drilling to extend every fourth or fifth line.

References

- Jackson, Chas. F., and Knaebel, John B., 1934, *Small-Scale Placer Mining Methods*: U. S. Bureau of Mines, Information Circular 6611, Sixth Revision
Peele, Robert, 1941, *Mining Engineers' Handbook*, 3rd Ed.: John Wiley and Sons, Inc., New York
Purinton, C. W., 1905, *Methods and Costs of Gravel and Placer Mining in Alaska*: U. S. Geological Survey Bull. 263

Savage, E. M., 1934, *Prospecting for Gold and Silver*: McGraw-Hill Book Co., Inc., New York

Wimmler, Norman L., 1927, *Placer Mining Methods and Costs in Alaska*: U. S. Bureau of Mines Bull. 259

Chapter 13

SINKING PLACER PROSPECT SHAFTS

SINKING SHAFTS IN FROZEN GROUND

Frozen ground, which is more difficult and expensive to mine than thawed ground, is easy to prospect because the frozen ground can be drilled, sunk in, or drifted in with as much safety, and holds up as well as if it were solid rock. Unlike solid rock, however, it can be converted to thawed gravel, which can be shoveled easily. Frozen gravel does not lend itself well to drilling and blasting, because it thaws slightly during drilling and tends to stick the bit. However, certain "dry frost" or material having a low moisture content is sometimes drilled and blasted.

After the prospector has decided where to sink the hole, he chops off the moss or tundra with an axe, grub hoe, or special wide hoe made for this purpose. The hole is squared up about three feet wide by five feet long, and a collar of logs laid around it, against which moss and dirt are banked up. This collar keeps rocks and dirt from falling into the hole, provides more room for dirt removed from the hole, and forms a solid base for the windlass. There are now two ways in which the sinking may proceed; picking and thawing. If the ground consists of muck, with much ice, it can be picked almost as fast as it can be thawed. If wood is difficult to obtain this course may be the best to follow. The muck and ice are picked loose with a sharp pick and shoveled from the hole. A tool useful for breaking off projections of muck is a gad, or wedge-shaped instrument which may be driven or hammered.

If gravel is encountered, no further progress can be made by picking, and the frozen gravel must be thawed by a wood fire, by dropping hot rocks into the hole, by hot water, or by introducing steam from a boiler. Each of these methods will be considered shortly, but first the equipment needed is described.

Equipment

A No. 2 round pointed shovel, cut to about three feet, and a miner's pick are used in the hole. As soon as the hole is too deep for the dirt to be thrown out, a windlass is built. This device is simple and can be made with an axe if necessary, although a saw, wood auger and chisel are useful. The windlass bucket is of wood or steel. The steel bucket is safer, and because it is watertight can be used to hoist water as well as dirt, keeping the hole drier than the wooden bucket will. The wooden bucket is square, about twelve to eighteen inches across the top, and tapered toward the bottom. It is built of one inch lumber, and can be any convenient size that will fit in the hole. Two holes are drilled near the top on each side, and a rope threaded through them so that the pull is taken up by all four sides. The rope is spliced, and is left long enough to leave a handle on each side that will reach to the middle so that each rope handle can be caught by the bucket hook.

The steel bucket is usually cylindrical, about a foot in diameter and a foot to eighteen inches deep, made of 16 gauge steel, with strap iron reinforcements. The bale is made of strong steel rod, fastened to ears on each side of the bucket, and has a loop at the top, so that the bucket hook will always catch it in the center. The bucket hook may be any of several strong hooks made so they cannot be accidentally unhooked, but the commonest is the "serpentine" hook, which makes a full curve. Fig. 13-1 illustrates buckets.

Occasionally two buckets are used, each on a separate line at opposite ends of the windlass drum. As the full one is raised, the empty one is lowered, acting as a counter weight.

On almost every creek on which drift mining was practised, one or more self dumping buckets and carriers can be found. Three main types were developed: one in Dawson and two in Fairbanks. Usually, for prospecting, it is not economical to set up a self dumping plant, but if the shaft is deep, and if the equipment can be obtained very cheaply, it may be worth while.

The type built by the Northern Commercial Company in Fairbanks consists of the following: (1) a carrier riding upon a highline leading from a gin pole over a headframe at the shaft to a deadman, and (2) a bucket that rides upon the bight of the hoistline in the shaft; while above ground it is locked to the carrier so that it can ride the highline to the gin pole. There is also a hoist, powered usually by steam, since steam normally is needed for thawing. When sinking in dry thawed ground, the prospector may use a gasoline engine.

The operation of the unit may be understood by referring to Fig. 13-2 in conjunction with the following description. The carrier itself rides the highline from the headframe to the gin pole.

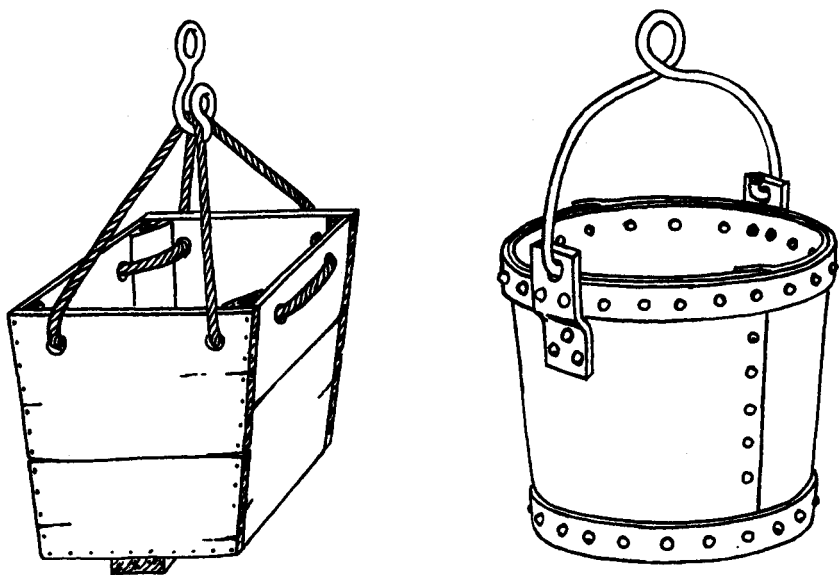


Fig. 13-1 - Wooden and Steel Windlass Buckets Showing Serpentine Bucket Hook.

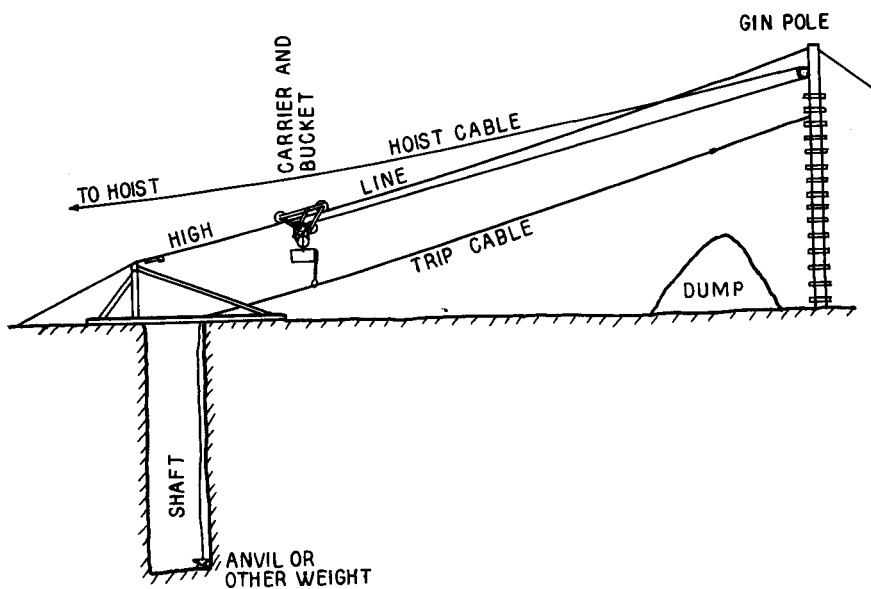


Fig. 13-2 - Arrangement of Self-dumping Carrier and Bucket for Shaft-sinking.

The hoist cable is fastened to the carrier and goes through a sheave on the gin pole, to the hoist. When the bucket is in the hole, hanging from the sheave on the bucket under which the hoist line passes, pulling on the hoist line raises the bucket. As long as the bucket is in the hole, the carrier is held fast to the highline by a catch. When the bucket reaches the top, a rod on the frame above the bucket sheave strikes a cam, which rotates enough for a recess in the cam to engage the rod. When the cam is in the proper position to hold the rod and with it the bucket, a dog drops down, locking the cam in position. At the same time, the carrier is unlocked from the highline so that it is free to roll. From this point on, the hoist line pulls the carrier with attached bucket up the highline. A guide cable reaches from the bottom of the shaft, over the collar, and to the gin pole, a few feet below the highline and parallel to it. Two choins, one from each of the two forward corners of the bucket, are attached to a ring sliding on the guide line. Near the gin pole an obstruction is clamped to the guide line, and as the ring strikes it, the bucket dumps. The carrier and bucket are again lowered to the shaft, where a trip on the cable forces the dog away from the stop on the cam, allowing the cam to turn and free the bucket. The bucket is then lowered down the shaft.

As stated previously, such a plant is seldom used for prospecting. The bucket is too big for a small prospect shaft; there is too much deadwork involved in setting up; and the lower end of the guide cable must be constantly shifted as the hole is deepened. (Sometimes it is anchored with an anvil). If a prospect hole becomes so deep that windlassing is too slow, it is better to use a regular shaft sinking bucket with a small gasoline engine-powered hoist.

Ladders are made as needed, from twelve to eighteen inches wide and any convenient length from six to twelve feet. The best and safest ladders are made from flattened timbers, about two by four inches, drilled for each rung. Rungs also may be nailed to the side pieces instead of inserted in holes, but in any event the ladder must be strong. It should be remembered that a ladder at the bottom of a shaft one day may be forty feet above the bottom several days later. Fig. 13-3 shows two types of ladders.

Although prospect boilers are of several makes, shapes, and sizes, in general they fall into two categories: the doghouse boiler, and the porcupine boiler. The doghouse boiler, as its name implies, has a rectangular shape with a front door. The outer covering is of sheet metal lined with asbestos. Pipes running lengthwise are connected together at their ends, and are arranged along the sides, top, back, and sometimes bottom. These pipes are connected to the dome, a larger pipe (four to six inches in diameter) about two feet long, set vertically in the smokestack which rises from the top of the boiler toward the back. As the water in the small pipes is heated and boiled, steam collects in the dome above the water, and is bled off through a hose or pipe.

The porcupine boiler has a cylindrical cover. The top forms an inverted funnel, with the stack representing the small part of the funnel. The porcupine boiler is essentially a vertical dome about three or four feet high, into which are drilled random holes. Short pipes are threaded into the holes. These pipes, capped or battered shut, suggest porcupine quills, hence the name.

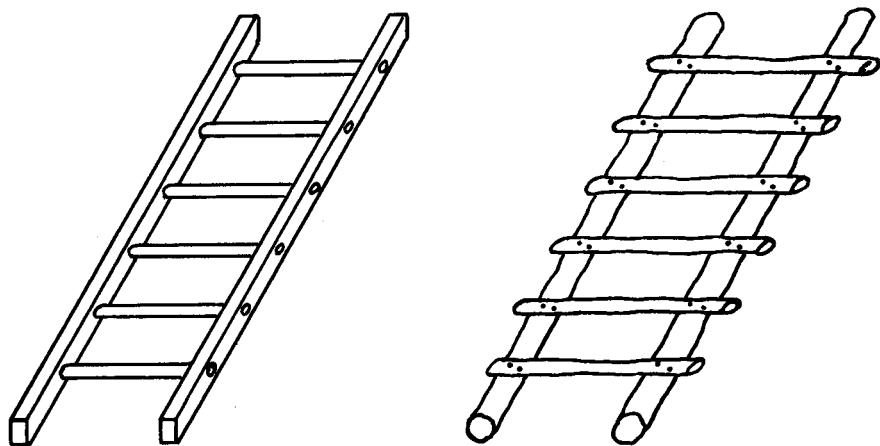


Fig. 13-3 - Ladders

Most prospect boilers are open on the bottom so that a wood fire can be built on the ground inside the boiler. In the few localities where coal is obtained cheaper than wood, grates may be placed in the boiler to facilitate burning coal. Boiler capacity is measured in boiler horsepower (bhp). A boiler is of one bhp capacity if it can convert thirty pounds of water into steam in one hour. Another method of estimating bhp is to divide the square feet of heating surface by ten. Both methods give approximate results.

Water is injected into the boiler from the bottom by a hand pump or a steam injector. The hand pump is a small pump, usually machined from brass and steel, with a solid plunger which sucks water into a piston through a check valve on the upstroke. Suction is insured by a gasket squeezing against the piston. On the downstroke, the intake check valve closes, and the displacement of the water by the piston in the cylinder forces it through another check valve into the boiler. The most widely encountered variation of this pump is mounted on a doghouse boiler manufactured by the Northern Commercial Company. It is mounted in a square water tub on top of the boiler and must lift water only about one inch. Another type of hand pump, about the size and shape of a tire pump, is operated on the ground beside the boiler. Water is pumped into the boiler by hand when the level in the glass gauge drops.

The injector usually used on a prospect boiler is the automatic type, so called because turning on the steam automatically starts it. The most common injector is the "Penberthy". The principle upon which the injector operates is that a rapidly moving jet of gas or liquid (in this instance, steam), drawn from a separate outlet near the top of the dome, will tend to drag with it a part of the gas or liquid through which it is moving. In the Penberthy automatic injector, there are three jets in line with each other, but separated from each other by small intervals. Steam rushing across the first interval sucks the air from the space surrounding the interval. The feed water pipe is connected to this space, and water flowing in to fill the space is dragged along by the steam jet into the second, or combining tube. Leaving the combining tube, the mixed steam and water encounter a third tube, perforated by holes, and separated from the combining tube by a small gap. The steam and water rush through the gap and perforations into an enclosing space, and force open a swing check valve from where they discharge through an overflow pipe and are wasted. When the water entering the third tube acquires a sufficient velocity from the steam jet (which has been condensed in the water) it passes through the third tube without escaping through the perforations. It then passes to the boiler feed pipe and forces open the check valve located therein and enters the boiler. As soon as this happens the swing check valve to the overflow closes, and all water entering the injector passes through to the boiler.

No part of the boiler gives so much trouble for so little reason as does the injector. The following are offered as suggestions.

1. See that no encrustation has built up in the injector. Scrape the injector out or immerse it in dilute hydrochloric (muriatic) acid; remove from acid when bubbling stops, otherwise the brass will be attacked.
2. Examine internal parts for nicks, deformations and wear; see that check valves are working freely and seating tightly.
3. See that intake and outlet pipes have tight joints, and are not plugged. Check the intake screen for plugging also, and see that the check valves are free.
4. Because the water enters a partial vacuum in the injector, it boils at a lower temperature than at ordinary pressures. Too warm feed-water will vaporize and stop the operation of the injector. If cool feed-water has been provided but the water in the feed pipe becomes hot, escaping steam is indicated; check for the leak.
5. If too much steam is supplied, it will issue from the overflow, and the quantity should be reduced.
6. Injectors are designed to work between certain pressures; in practice an automatic injector requires at least forty pounds pressure.

Some of the rules applying to the operation of injectors, such as seeing that pipes and check valves are unclogged, apply equally well to hand pumps. Beyond these simple precautions, little need be done to keep the hand pump working year after year. When using a boiler in remote areas, far from shops, therefore, the hand pump is preferred to the injector. Its only disadvantages are the labor required to operate it, and the fact that the water is not pre-heated. On the other hand, the fact that the hand pump uses no steam probably cancels the added fuel consumption due to the lack of pre-heating the water. The Penberthy injector and a simple hand pump are illustrated in Figs 13-4 and 13-5.

Besides the injector or pump, each boiler should have the following accessories: A glass gauge situated at such a level that it will be full of water when the boiler is sufficiently full; a pressure gauge on an outlet from the steam dome; a safety valve, usually set to open at 125 pounds, mounted on a steam outlet; two steam outlets, each with its own valve, one to furnish steam for thawing, and one to furnish steam for melting snow for boiler water in the winter, or for warming up feed pipes, water, etc.; a water intake, whether serving a pump or an injector, covered with a screen to keep out solid material which might clog the pump, injector, or check valves.

In addition to these boiler accessories, every spot where water might accumulate is provided

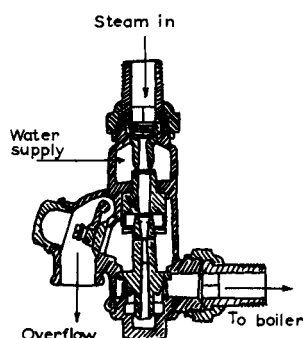


Fig. 13-4 - Penberthy Steam Injector

with a valve or stop cock so that the boiler can be completely drained at the end of each thaw. Failure to drain results in cracked pipes in freezing weather. Some boilers are also equipped with try cocks, stop cocks arranged at equal intervals vertically on a pipe alongside the glass gauge. If the glass gauge becomes broken, the water can be shut off above and below by valves. The amount of water in the boiler is then determined by opening one or the other of the try cocks and seeing which spurts water and which spurts steam. A doghouse boiler is shown schematically in Fig. 13-6. See also Fig. 17-3 for photo of boiler.

Other accessories are necessary for getting the steam from the boiler into the ground. The steam pipe is usually 3/8 inch diameter pipe in convenient lengths, up to ten feet long. It may be wrapped with asbestos or cloth to save heat. A 3/8 inch inside diameter steam hose is used to bring the steam from the boiler to the pipe and is held on the ends of the pipe and to the steam outlet on the boiler by steel hose clamps, which are tightened by 1/4 inch cap screws. The lower end of the pipe is connected to the steam point through a similar hose. The hose is clamped to the steam point by any one of a number of methods, depending on the type of point used.

Points differ only in the shape of the bit and in the method of attaching the hose. Bits are either chisel-shaped or square. The chisel-shaped bit is best for coarse gravel where many rocks must be drilled by the point, although the square bit is fairly effective in drilling rocks. The point itself is a round hollow tool steel stem usually 7/8 inch or one inch in diameter and from four to twenty feet long. Points longer than about eight feet are usually used only when thawing from the surface. Underground, points from four to eight feet long are used. The upper end of the point is solid steel, about 1 1/2 inches in diameter and a foot long, welded to the thin hollow part of the point. Steam is introduced into the point through a hole drilled into the upper solid part, connecting to the hollow point.

Probably the most common point is the nipple point, that into which steam is introduced through a nipple welded to the upper part at right angles to the length of the point. It has the advantage of simplicity and having no small parts to get lost, but the nipple may be broken off if it is accidentally struck by the hammer in driving, or if a strain is taken on it in pulling. There are several types of points having detachable hose connectors, most of them developed in Fairbanks. The best known of these is the Barrack point. The point has a clamp which is fastened to the hose; the clamp is then bolted to the solid part of the point.

Two other items used in steam thawing are the point hammer, a four pound machinist's hammer or single jack, and the turning bar, a tool steel rod which is put through a hole in the and used to turn the point as it is being driven. The bar is sometimes made from

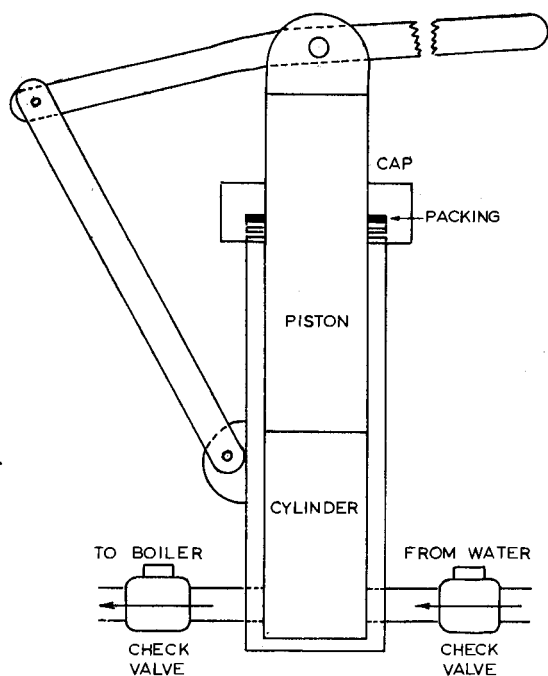


Fig. 13-5 - Schematic Diagram of Boiler Handpump.

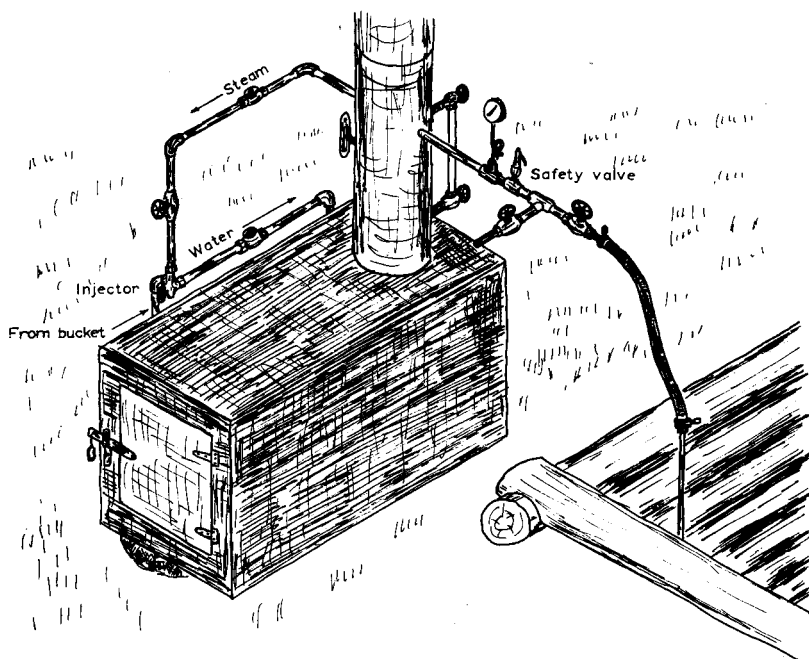


Fig. 13-6 - Schematic Layout of Doghouse Boiler Showing Exterior Piping. When handpump is used it is inserted in place of injector, and steam pipe to injector is plugged.

a pick.

A boiler house is not absolutely essential, except in very cold weather. Nevertheless, even in the summertime, the efficiency of the boiler is increased by providing some shelter, if only a windbreak, for the boiler. In cold weather, keeping the intake lines from freezing is a problem; and if no shelter is available, a blow torch should be kept ready for thawing pipes.

Methods and Techniques

THAWING - When no more muck can be picked (gravel or slide has been encountered), the prospector decides which method of thawing he must use. Where one man is working alone, he may decide that woodfiring is the best method, especially when the hole gets deeper than ten or fifteen feet, because he will be spending considerable time climbing the ladder, and the amount of dirt which he can conveniently remove during a day is just about as much as will thaw by a single wood fire. An added advantage, if the prospector decides to use woodfires instead of steam, is that he does not have to haul a boiler onto his creek. Woodfires, however, are slow, and at times dangerous. They can be used only during cold weather, when good circulation is insured; otherwise, poisonous gases may collect in the bottom of the shaft. Ventilation is improved by a tarp slung at the surface in such a way that wind is deflected into the hole, and sometimes a curtain is hung in the hole, dividing it in the center so that air may move down one side and up the other.

The wood for the fire should be very dry, cut into two foot lengths, and split finely, about one inch thick. The bottom of the hole should be as dry as it can be made; dry shavings laid in the center, and an armful of wood piled over them. Two or three pieces of sheet iron should be laid over the wood so that they will protect the fire from falling rocks or dirt, yet not smother it. The kindling is lit, and the fire left to burn. Flat rocks can be used to protect the fire and direct the heat if sheet iron is not available. The rocks have an advantage in absorbing heat which is given up to the ground as they cool. Fig. 13-7 shows the top of a shaft which is being sunk by woodfires.

Opinions differ as to the best way to build the fire. For sinking prospect shafts, the method described above is probably best. A small, hot, quick fire burns out fast and imparts its heat to

the rocks in the gravel, which thaws the fine material between the rocks after the fire burns out. If the fire is built in the evening, by morning almost the maximum thawing has been attained, and the hole can be cleaned out. In the Bonfield district where coal was available, the prospectors developed a method of using coal for thawing. They got good results as the coal and ashes held the heat well. Green wood has also been used piled over the dry wood, but this practice leads to a slow fire with consequent sloughing of the sides, and in a drift, the back will slough.

A little practice soon provides the prospector with the information he needs to tell him how big to build his fire to thaw a hole four feet in diameter.

The ground can be thawed with rocks which are heated in a fire at the surface, and dropped into the shaft, but this method is costly in wood and entails hoisting the rocks after they cool.

A method, not commonly practiced, but worthy of more consideration, is the use of hot water for thawing. The simplest system is to heat water in a barrel (see Chapter 14 for details of building an efficient water boiler), and pour fifteen gallons down the hole. It should be left until cooled, so that the maximum heat has been extracted; then the hole is mucked out. By this me-



Fig. 13-7 - Preparing to Build a Fire in the Shaft.

thod, in the Innoko district, shafts have been sunk through medium coarse gravel with the following results. Fifteen gallons of water were used. The ground took one and one half to two hours to thaw; then two men cleaned the hole in thirty minutes. Six to eight inches were advanced on each thaw. The average number of thaws was a little over three per day, making an advance of about two feet per day for two men. Two or three holes should be sunk at once by this method, as tending the fire and hauling water would not keep two men busy during the time the ground is thawing between cleanings of the hole.

Hot water may also be pumped into the ground. A hand piston pump is procured or built (the type of hand pump used with the prospect boiler is satisfactory) and mounted to pump from a barrel. A hose is run from the pump to a point. The water in the barrel is heated and pumped to the point which is pushed or gently tapped down. In muck, a long sweeter is made up of steam pipe coupled together, and driven to gravel. Hot water is pumped in for about an hour for each foot of depth, and the thaw allowed to stand for a day to ensure all available heat being extracted from the water. Thawed muck is usually removed by baling with a bucket.

When thawing with steam using the wood burning boiler, the prospector first levels the site and sets the boiler level on flat rocks two or three inches above the ground. Dirt is then piled around the boiler to seal off air leaks at the bottom. A hole for a draft is dug under the door, and a piece of tin for regulating the size of the draft opening is obtained. In freezing weather a small fire must be built in the boiler to warm the pipes before the boiler is filled with water, but in warm weather this is not necessary. Boiler wood should be dry, but need not be as dry as that used in wood firing.

If the boiler is provided with a pump, water is pumped in; if with an injector, water is poured into the boiler at some high point, usually at the safety valve, which is removed and replaced after the filling. The fire is stoked until steam is obtained.

While steam is being built up, one end of a ten to twelve foot length of steam hose is clamped to the steam outlet pipe and the other end to the steam point. This clamp must be wired to the point to keep the hose from working off during driving. As the hole is deepened, 3/8 inch pipe is extended down the hole. (All steam pipe threads are lubricated with oil and graphite.) If available, it is convenient to have a steam valve at the lower end of the pipe so that the point driver can turn on the steam when he reaches the bottom of the hole. This valve is especially necessary when one man works alone, because if he must turn on the steam at the boiler, then climb down the shaft, the hole will be full of steam when he reaches the bottom.

A pebble is dropped from the center of the windlass, or a plumb-bob suspended to find the center of the hole. The point is placed in this spot, the steam turned on, and the point twisted and pushed down. In muck, the point will sink home almost as fast as it can be pushed, but in gravel, it must be driven.

After the steam has had time to thaw a little ahead of the point, the top of the point is struck with the point hommer, and the point is twisted with the bar. The point works its way down between the rocks, and drills through them when necessary. In tight gravel, it may take several hours to drive home the point. If a pebble plugs the point, the point should be drawn out and struck on the driving head several times while the steam is turned on to clear the point. If a rock is struck close to the surface which is too big to be drilled by the point, it may be advisable to move the point over and drive it so that it angles under the rock. If the rock has been encountered at some depth, the only thing to do is to stop driving and let the hole thaw. The depth of thaw will be less than usual, as only part of the point is in the ground. The time of thawing is reduced accordingly. The rock is removed when the thaw is mucked, and the work progresses.

Steam pressure is kept at fifty to ninety pounds. A hole in gravel is steamed from one half to one hour for each foot that the point is in the ground. Sand requires more time to thaw, and muck requires even more time, especially if ground ice is present. After steaming the center about a half hour to the foot, each corner may be steamed to produce a rectangular hole. Dry superheated steam does not thaw as well as saturated steam. For the last hour or so of the thaw, the point is pulled up by two foot increments so that the upper part of the thaw will not be too narrow. If two points are available, they are driven about 2 1/2 feet apart, thawing an elliptically shaped hole. Steaming time is reduced with two points.

The point driver should guard against the possible danger that water accumulating in the hole may become hot enough to burn his feet. Consequently, the driver should stand on a ledge or a stool. Snow, when available, is sometimes thrown down to cool the water, but this wastes heat. During the last half hour of the thaw, the fire is allowed to burn out, so that only a bed of coals is left when the thaw is done. When the fire is thus reduced, the amount of steam going to the point must be reduced so that pressure is maintained. Steam valves are always opened or closed slowly; otherwise an explosion may result.

In loose ground the point can be pulled out by merely lifting and twisting, but in tight ground it may be necessary to take a strain with the windlass, and tap upon the turning bar. The cable should never be placed in such a way that the pull is on the nipple, as the nipple breaks off easily, but rather, the strain should be put on the turning bar on the shank of the point itself.

When the thaw is completed, the point is pulled out of the ground, the steam shut off, and

the point and hose disconnected and hoisted out. The valve at the bottom of the boiler is opened and the water ejected under pressure. All steam valves and petcocks are opened, and the fire, which by this time should be only a bed of coals, allowed to die out by itself to provide enough heat so that the boiler is dried out, an essential operation in freezing weather. The 3/8 inch pipe extending down the shaft is tied to the stulls with the ladders and is not removed.

If wood is scarce, the hole is left for a day so that the heat stored in the rocks and water is completely utilized in thawing. The thawed material is then removed. It sometimes happens that the prospector has misjudged the amount of steam to give the thaw, or driven the point off center, so that the hole must be straightened or enlarged. During the next thaw, while the ground is steaming, hot water from the shaft is dashed and poured against the walls until they have been enlarged to the proper size and shape. After the water is cooled, it is bailed out. A man working alone may bail without climbing into the hole by weighting one side of the bucket so that it will tip when it hits the water.

If a boiler is not available, it is possible to steam with a heavy duty, fifty three gallon drum. It should be fitted with a pressure gauge, and the pressure kept below 30 pounds per square inch, as the drum is not nearly so strong as a boiler. Because of the low pressure, the point must be driven very carefully to avoid plugging. If the point becomes plugged, the steam stops flowing and the pressure builds up rapidly. It is always possible to tell if steam is flowing by pressing an ear against the steam hose; a hissing sound indicates flowing steam.

A point may be made to do double duty by pulling it up after it has been driven home, and substituting a sweeper for it; the point is then available for driving elsewhere.

Fig. 13-8 shows a prospect boiler in operation and Fig. 13-9 illustrates the arrangement of equipment in a prospect shaft.

CLEANING THE HOLE - After thawing, the hole must be cleaned out, or mucked. First any water collection is bailed out and hoisted in a water bucket or in a steel windlass bucket. The thawed dirt is then picked loose, shoveled into the bucket, and hoisted. If two men are working together, one stays in the hole while the other hoists and dumps. The man in the hole should watch the bucket, and have enough room to avoid being struck by falling dirt, or by the bucket

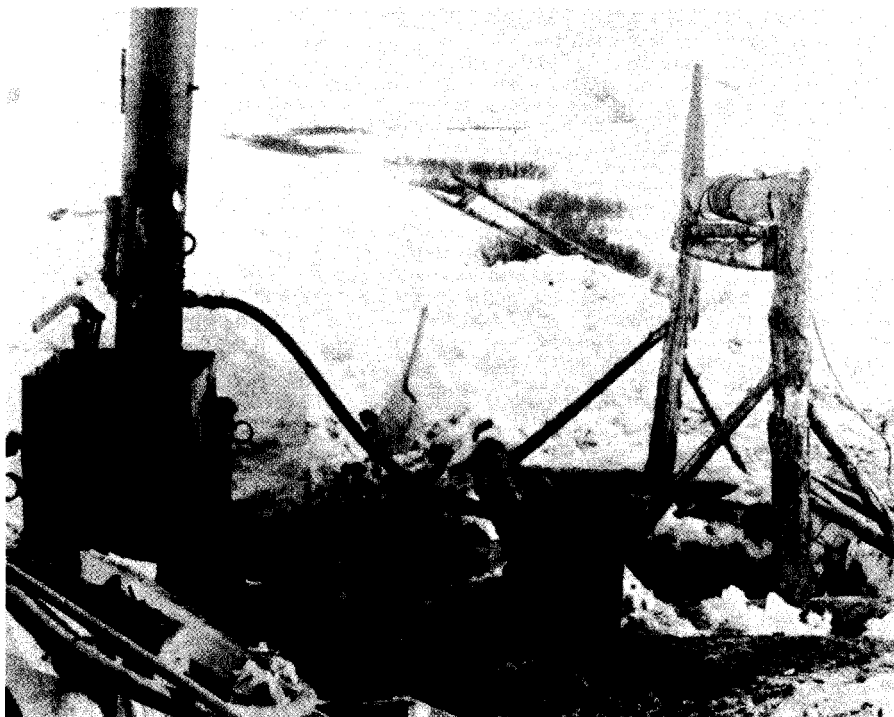


Fig. 13-8 - Doghouse Boiler in Operation

in case of accident. If a man is working alone he climbs the ladder, hoists the bucket, dumps, lowers it down, and climbs down to start all over.

If a rock is encountered which is too big to go into the bucket, the rope is hooked around it for hoisting. There should be no one in the hole while a boulder is being hoisted. If a boulder too big to be hoisted is struck, and cannot be broken by heating or sledging, it must be blasted and removed in pieces. There are four ways to do this: mudcapping, snakeholing, blockholing, and using shaped charges (see Chapter 16).

As seen from the table on page 306 Chapter 16, blockholing is most economical in power consumption, but it requires more labor. When blockholing, furthermore, it is necessary to have rock drills on hand, which in turn necessitates having a forge, anvil, and coal. A Canadian Company is now making handsteel with tungsten carbide tips, which are good for a whole season. The use of such a drill makes it unnecessary to have a forge for sharpening. The cost in time and in dynamite must be balanced against each other when deciding which method to use.

It may be possible to break a boulder with a sledge hammer if there is room to swing, and this technique should always be tried first if it appears practicable. Alternately heating with fire and chilling with water sometimes causes a boulder to break. The fire is built on the rock, and after a suitable interval, cold water is poured down the hole. This method cannot be used on large boulders. Rocks and boulders left frozen into the sides of the hole should be tapped with a hammer periodically. A rock solidly frozen to the walls give off a clear sharp sound, but one which has thawed loose, and which therefore presents a danger, gives off a dead sound.

The prospector repeats the procedure day after day, thawing with woodfire, hot water, or steam, and hoisting the thawed dirt, breaking boulders where necessary, until he reached bedrock. As the depth of the hole increases, another ladder is added from time to time. The top ladder is lashed to the windlass frame. At the bottom of the top ladder the prospector places a stull, a pole, two to four inches in diameter and two to four feet long. It is placed against one side of the shaft, where it will not interfere with the bucket, and tipped slightly from the horizontal. A recess (hitch), large enough to take the lower end of the stull, is picked out on one side, and a groove into which the upper end of the stull can be jammed, on the other side. The stull jammed into the hitches, makes a strong support, but to be sure that it cannot slip out, wet mud may be packed around each end, which soon freezes and seals in the stull. The bottom end of the ladder above, and the top end of that below, are lashed to the stull, and the work progresses. Stulls are placed as each ladder is added.

Material from the bottom of the hole should be panned after every thaw, or whenever the character of the material changes, and a record kept of the relative amounts of different minerals in the concentrates. A sketch of the hole is also made as work progresses.

After the hole has been bedrocked (extended to bedrock), the prospector may wish to explore a larger area than is available at the bottom of the shaft. In areas where the bedrock is schist, or other foliated or bedded rock, large slabs may slide into the gravel, especially on creeks with steep sides. When bedrock is encountered, it is always a good idea to uncover enough of it so that the strike and dip of the schistosity can be determined and compared with the known attitude of outcrops in the neighborhood. The slope of the surface also is helpful in determining whether the rock is slide or bedrock. If the slope of surface and dip of schistosity are different from what should be expected, the hole should be deepened until the prospector is satisfied that he has reached bedrock. He then begins to crosscut, or drift at right angles to the length of the creek. Thawing with standing hot water cannot be practiced in drifting. If steam is used, the point is driven horizontally about two feet above bedrock. If wood fires are used, the fire is built on one side of the shaft; kindling is piled on the floor, against the face, and the wood is piled over it. Flat rocks or sheets of iron are leaned against the face to protect the wood and keep the heat in. A small quick fire gives a minimum of

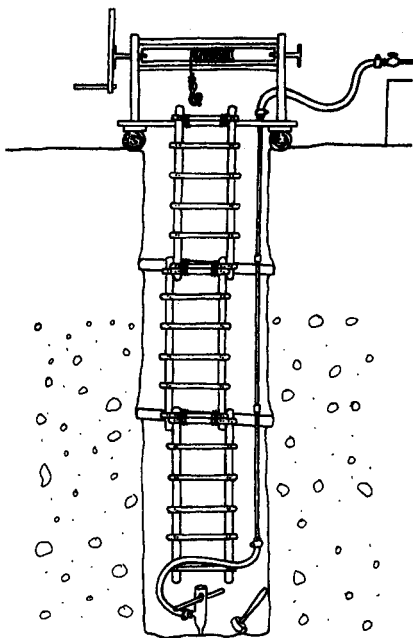
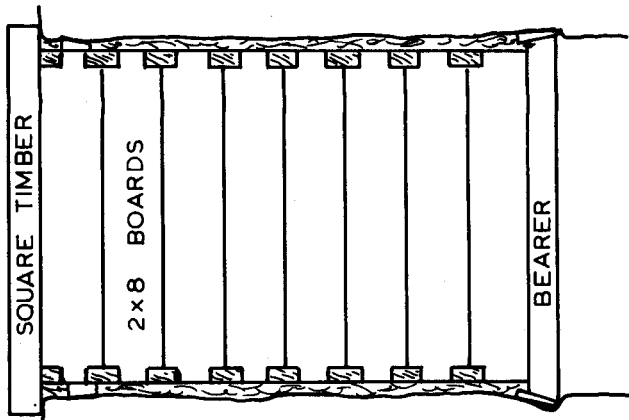
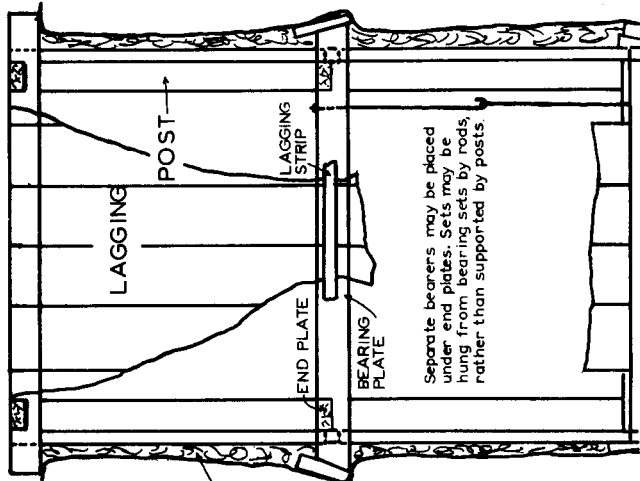


Fig. 13-9 - Placer Prospect Shaft

BOARD CRIBBING



TIMBER SETS



LOG CRIBBING

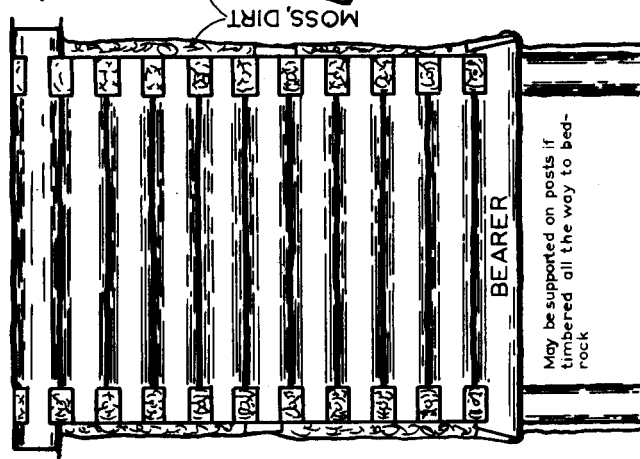


Fig. 13-10. - Shaft Timbering: Cribbing and Sets

sloughing from above. The wood is laid horizontally with the ends overlapping. When a longer face is carried, as in drift mining, the face is concave inward, so that more face is presented to the fire. The fire is lit at both ends. Larger boulders in the back of the drift should be supported with posts for safety.

Two poles held about six or eight inches apart by cross pieces are used as skids on which the bucket is dragged from the face to the shaft, and from the windlass to the end of the dump. The wooden bucket has a three inch board nailed to the bottom, dividing it into two equal parts so that it will not slide off the rails. If the shaft has struck a steep rim and the prospector is drifting down the rim, it is difficult to drag the heavy bucket from the face to the bottom of the shaft. It may then be desirable to blast into bedrock at the bottom of the shaft so that the uphill drag is eliminated. When drifting from a hole in the prospect stage, it is not necessary to hoist all the material. Some may be left between the shaft and the face, so long as enough room is left for the bucket to be dragged through.

TIMBERING - In the winter, thawing at the top of the hole will not cause sloughing, but if operations continue into summer, the top of the shaft must be timbered. The simplest and strongest timbering is cribbing. A set (4 logs, notched at their corners, log cabin fashion) is started ten to twenty feet down, well below the depth to which thawing occurs. The inside dimensions of the timbered shaft should be about three by four feet. The two shorter logs of the bottom set are hitched into the walls, and the two longer logs are laid upon these, after having first been notched. They are then spiked to the shorter ones. This first set, which supports the cribbing, is a bearing set. From the bearing set upward, the cribbing is built like a log cabin, the corners notched and spiked to keep them from shifting. After every few sets or rounds of cribbing, timbers are hitched into the walls to form bearing sets. As the cribbing is built up, moss is laid against the logs and dirt is packed between the moss and the frozen walls. When the cribbing has been built to the surface, the top round becomes the collar. In close cribbing, the timbers touch, "skin to skin." In open cribbing a space is left between them. The shaft may also be cribbed from the top down as the shaft is sunk, but this is usually done only in thawed or weak ground.

Another type of timbering employing sets and lagging, is used more often in sinking shafts in hardrock, and consists of the following: A rectangular set of squared timbers is made, with notched corners. The shorter timbers are end plates, and the longer ones, wall plates. The end plates extend to the walls where they are wedged or preferably hitched into the walls. A set thus hitched into the walls is a bearing set. Poles about five feet long are placed vertically at the corners of the bearing set. These four posts support another set, which may be wedged to the walls, or may be hitched in as was the first set. Posts are notched into the sets, and spiked. Sets are installed every five feet, and poles, slabs, or boards are placed outside them as lagging. Lagging strips, nailed to the plates, hold up the lagging. Moss and dirt is packed outside the lagging to support the walls. Fig. 13-10 illustrates the two types of shaft timbering described, as well as board cribbing.

SEALING THE SHAFT - It is possible to keep a shaft open indefinitely in frozen ground if it is properly sealed. Sealing may be desirable for any one of several reasons: The shaft may not have been finished before the spring thaw; it is desired to crosscut from it later; it may be used later as a workshop; or the prospector may merely wish to preserve meat in it during the summer. While it is possible to keep a shaft open through a summer by laying poles across the top and covering them with moss, this method is risky in that water may seep in at the bottom of the seasonally thawed layer, filling up the shaft or causing it to slough.

The following is the only safe way to seal a shaft. Two timbers are hitched in several feet down, well below the depth of summer thaw, and a platform of poles is built upon them. The poles are covered with burlap or moss and a few inches of snow put over them. Water is sprinkled on the snow, making slush, which is tamped well around the sides of the shaft. The slush is allowed to freeze, and more snow is thrown on, watered, tamped, and allowed to freeze. The process is repeated until a plug of porous ice solidly frozen to the walls fills the upper part of the shaft. The plug is then covered with about a foot of moss and a trench dug around the uphill side of the shaft to lead water around and away from it. Any surface water which does flow past the shaft has no more chance of penetrating the ice core than it does of penetrating the permafrost around it. Even if the spring is well advanced, and no more freezing temperatures are expected, this method can be used to seal a shaft if snow can be obtained from a nearby snowbank. The thawing snow is piled in and covered, and usually enough will freeze at the bottom to form a water tight plug. See Fig. 13-11.

Determining The Tenor Of Ground In A Shaft

A shaft which has been sunk "on the money" should be used to evaluate the ground at that point. Many prospectors take a few pans and evaluate the ground by saying that they got "ten cent pans," or "five cent pans," or whatever the figure happens to be. If the number of pans per cubic yard of gravel in place is known (usually taken as 189 heaping pans per cubic yard), it can be said that the value per cubic yard of the ground at the shaft is the value per

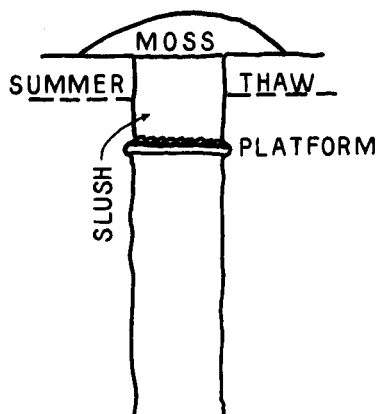


Fig. 13-11. - Method of Sealing a Shaft in Permafrost

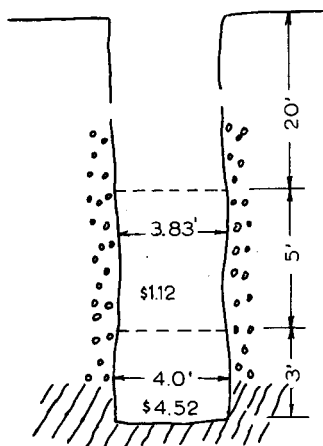


Fig. 13-12. - Measurements to Illustrate Calculations of Tenor of Frozen Ground

pan times the number of pans per cubic yard. This figure, however, is inexact and misleading. The best way to evaluate a shaft is to save the dirt from the hole in several separate dumps. The first dump should contain all the dirt taken from the shaft from the surface down to where the first prospect was obtained. The second should contain the dirt from there to bedrock, or better, two or more dumps should be saved while sinking through the pay horizon. The exact depths in feet and inches to the tops and bottoms of these sections should be recorded. When the hole is complete, each of these dumps is sluiced or rocked, and the amount of gold recovered from each section is recorded.

These depths are marked in the shaft, and several diameters are measured in each section so that an average can be obtained. The average area of the hole for each section is then computed, which, multiplied by the height of the section gives the volume in place. The value of gold recovered from that section, divided by the volume in cubic feet, gives the value per cubic foot, which when multiplied by 27 gives the value per cubic yard.

Suppose a shaft is twenty eight feet deep, with a roughly round cross section. The bottom eight feet contained the pay, and the dirt from the pay horizon was divided into two samples: the top one five feet deep, the lower one three feet deep. The top section had an average diameter of 46 inches, or 3.83 feet, and a radius, therefore, of 1.92 feet. See Fig. 13-12.

$$\text{Area} = (1.92)^2 \times (3.14) = 11.6 \text{ sq. feet.}$$

This figure, multiplied by the depth, yields the volume.

$$\text{Volume} = (11.6) \times (5) = 58 \text{ cu. feet.}$$

Now suppose that this section of the hole yielded \$1.12 in gold:

$$\frac{\$1.12}{58} = 1.93\text{¢ per cu. foot}$$

$$(1.93\text{¢}) \times (27) = 52\text{¢ per cu. yard}$$

The bottom section, three feet deep, is assumed to be exactly four feet in diameter:

$$\text{Area} = (2.0)^2 \times (3.14) = 12.5 \text{ sq. feet}$$

$$\text{Volume} = (3) \times (12.5) = 37.5 \text{ cu. feet}$$

Assume a yield of \$4.52 in gold.

$$\frac{\$4.52}{37.5} = 12\text{¢ per cu. foot}$$

$$(12\text{¢}) \times (27) = \$3.25 \text{ per cu. yard.}$$

It is decided to mine the whole eight feet of pay, so the volumes are added and the values

are added to get a new volume and value to compute a new value per cubic yard.

\$1.12 from upper section
4.52 from lower sections
\$5.64 from both sections

58 cu. ft. from upper section
37.5 cu. ft. from lower section
95.5 cu. ft. from both sections

$\frac{\$5.64}{95.5} = 5.9\text{¢ per cu. ft.}$

$(5.9) \times (27) = \$1.60$ per cu. yard for the bottom eight feet of hole.

If the ground is to be worked by open cut methods, the value per cubic yard for the whole depth must be known. The volume of the first twenty feet need not be computed, for no gold (or a negligible amount) was obtained from it. It need merely be said that if eight feet has a value of \$1.60 per cu. yard, 28 feet has a value of $(8/28) \times (\$1.60) = 46\text{¢ per cu. yard}$.

When the sinking of holes with caissons in thawed ground is discussed, a method is described of measuring volume by counting the number of one cubic foot buckets that are removed from a known volume in place. The volume of loose gravel removed from its natural bed is called the volume loose. The swell factor of the dirt is determined by measuring the volume loose of the material from one cubic foot in place and dividing the volume loose by the volume in place.

$$\frac{\text{Volume loose}}{\text{Volume in place}} = \text{Swell Factor}$$

The volume of dirt in place in the whole shaft is found by dividing the volume loose by the swell factor. If desired, this method may be used to measure the volume loose of the shaft through the pay horizon in frozen ground, but it is not as accurate as making actual measurements.

SINKING SHAFTS IN THAWED GROUND

If the ground which is to be prospected is thawed, the job is much more difficult than if it is frozen. The best solution probably is to drill it, but if, for various reasons already discussed, drilling is undesirable, and if the ground is relatively shallow, there are ways of sinking a hole.

Freezing Down

The method which requires the least amount of equipment, (but which is very slow), is freezing down a hole in the winter. After the winter frost has set in, a shaft is started by the wood fire method, and carried down until the winter frost is passed. The shaft is then sunk through thawed ground until the water table is reached. The hole is left for a day or two, the time depending upon the temperature, and allowed to freeze. A small fire is then built in the bottom of the hole, and the thaw cleaned out. Judgment is required in determining the size of the fire, so that it does not thaw more than is frozen. The hole, of course, must be kept clear of snow, as snow insulates it and keeps the bottom from freezing. Sometimes, to aid in judging the size of the fire, a bar is driven through the frost to judge the thickness, and the hole plugged with rags. If a thaw ever breaks through the frost, the water will rush in and the hole will be lost, a danger also encountered in sinking shafts in partly frozen-partly thawed ground. (It is called being drowned out.) As the hole is deepened, the ground freezes slower, but an average depth of freeze down to twenty feet is six to eight inches of freeze for each two days. A canvas curtain dividing the shaft, such as is sometimes used to ventilate, creates better circulation and speeds up the freezing.

As the hole must be finished in a single winter, and as the freezing becomes less efficient as the shaft is deepened, a "frozen down" hole is necessarily limited in depth. Twenty to thirty foot holes have been frozen down, but it is better to confine this method to shallower ground. Several shafts should be sunk simultaneously in order to use the prospector's time to full advantage. Ground prospected in this way is evaluated as frozen ground.

Winter frost has been utilized in a very interesting way on Porcupine Creek in the Koyukuk district. A drain was dug to bedrock, a depth of 28 feet. A section in the bottom about sixteen inches deep and sixteen inches wide was walled up, and covered with flat rocks and moss. The drain was then allowed to cave, leaving a covered drain. After the drain reached bedrock, it was cut sixteen inches into bedrock and carried upstream at bedrock grade, and covered at bedrock level. Great care was taken to see that the whole drain was absolutely water tight, otherwise, silt would enter and soon plug it. In the fall, about October 15 or 20, work

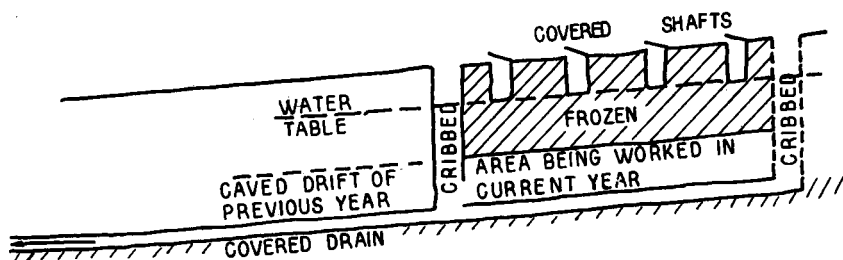


Fig. 13.13. - Method of Working Placer on Porcupine Creek by Utilizing Winter Freezing

commenced on twenty or thirty holes, spaced six or eight feet apart, covering that area of the paystreak which was intended to be worked out during the winter. These holes were sunk through the dry, thawed ground to the water level, eight or ten feet, requiring two men's time for about a day for each hole. To speed up freezing, the holes and the ground between them were kept free of snow; and holes an inch or so in diameter were punched through with a steel bar to connect the holes at their bottoms, allowing circulation of air. Each hole was fitted with a removable cover to keep out the snow.

By January first the ground was frozen to within six feet of bedrock. At the close of operations the previous year a tightly cribbed shaft was sunk at the upper end of the drain with the surface so that the drain could be reached. This shaft excluded all water from reaching the drain. In January, the head of the drain was opened (reached via the shaft), and the thawed area above bedrock allowed to drain. This area, about 2000 or 2500 square feet, was drifted out during the winter, the work being done under a perfectly safe frozen roof. Dirt was removed through the cribbed shaft at the lower end of the drift, and as the drifting progressed upstream, the drain was extended also. Work continued until about June 1, at which time the drain was extended upstream through the drifted area, walled up and sealed, and another tightly sealed shaft built from its upper end to the surface. The drift was then allowed to cave, and the next fall the process was repeated. From 1922, when the process was started until 1952, the drain was run 1100 feet. A schematic diagram of this operation is shown in Fig. 13-13.

A more elaborate method of freezing down a hole is sometimes used when it is desired to check the accuracy of drill hole data with a shaft. A cased drill hole is sunk into bedrock so that the casing seals out water at the bottom, and a two or three inch pipe is lowered to within a few feet of the bottom. This pipe is connected to a large radiator, such as might be used on a tractor. A fitting is made so that the top of the casing can be connected to the bottom of the radiator through a pump. The pump motor drives the radiator fan. Stoddard solvent or some other clean coolant is then circulated down the inside pipe and up the outside casing. A few weeks circulating in cold water is sufficient to freeze a cylindrical volume ten feet in diameter. Two men can sink a hole in the center of the cylinder and reach bedrock before it thaws.

Sinking Caissons

Another method of sinking a shaft in wet ground, one which can be used in the summer, is to sink a caisson, a cylindrical steel shell sunk into the ground to act as cribbing as the excavation proceeds. Caissons are not standardized; usually the prospector has them made to his specifications.

As it is difficult to work in a shaft less than three and a half feet in diameter, the smallest section (the one on the bottom) should never be smaller than this size. Each section is either four or five feet high, the higher ones being used near the top. The sections may be solid cylinders, or split to make them easier to transport. If split, they are made to overlap a couple of inches, and joined by bolts with rectangular heads (tee-bolts). These heads are of a shape and size to pass through rectangular slots in the shell. The bolt is turned 90° and tightened, putting the long dimension of the bolt head across the slot, locking the two parts of the section together.

The caisson is started by digging a hole big enough to take the topmost section, which is the largest. This section is wedged in and backfilled. If the water table has not been reached, the hole is deepened, and the next smaller section lowered into place inside the top section.

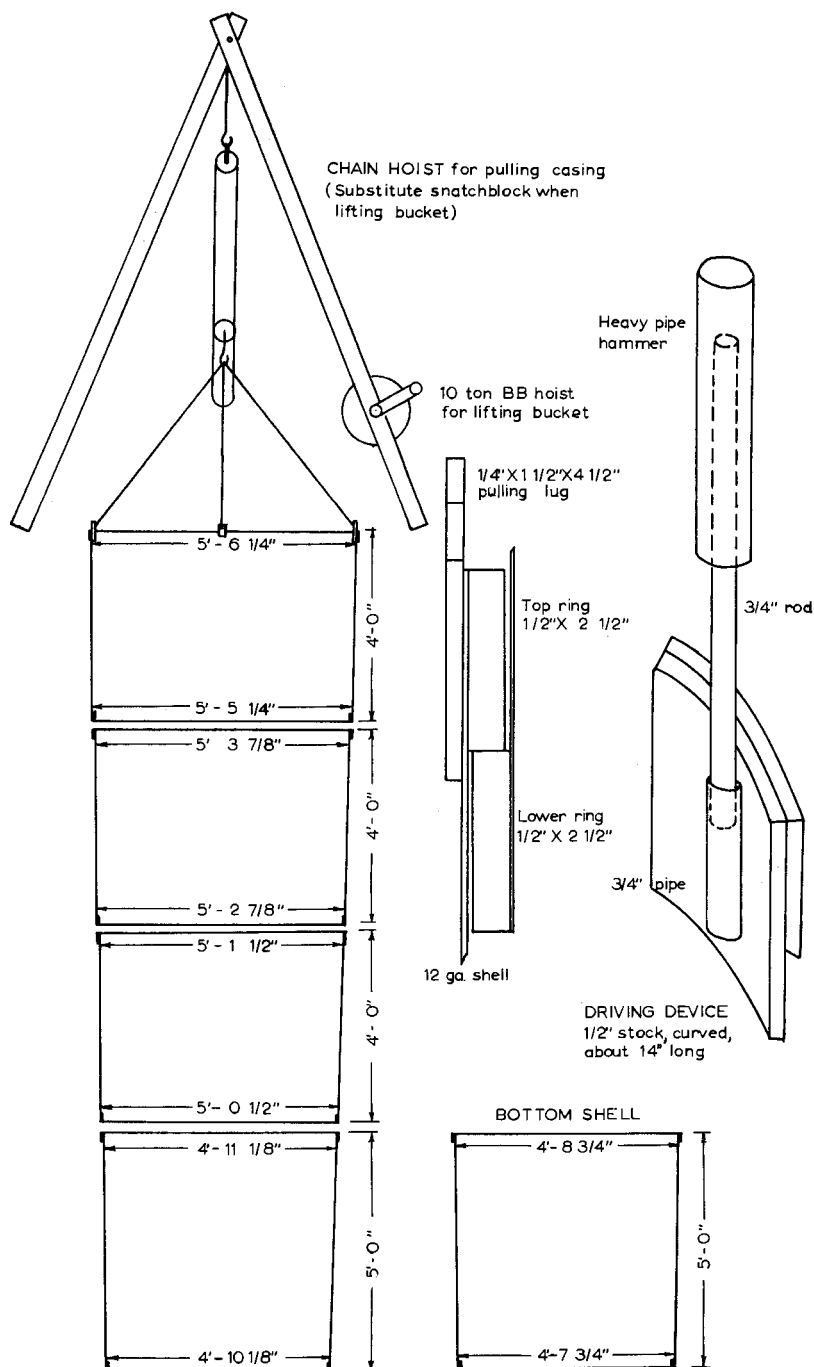


Fig. 13-14 - Caissons and Hoist

The top of this section has a rim of heavy strip or angle iron around the outside, which butts against a similar rim around the inside at the bottom of the section above. Each section may taper from top to bottom, as well as decrease in diameter from the section above. Tapered sections, of course are more expensive.

When the water table is reached, the work becomes more difficult. The section which will be needed next is lowered into the hole and leveled up. The man in the hole begins digging around the edges so that the caisson can settle, and the man on top hoists and dumps the bucket. The caisson is driven by hammering on a rod attached to a curved shoe which is moved around the top of the section being driven. Some drive shoes have a long rod attached, so the hoist man can drive on it while the man in the hole moves the shoe around. Others are short, and the man in the hole does the driving. When the flow of water becomes too great to be bailed, one or more pumps are started. When the flow of water is heavy, the pump should not be stopped, as much time would be wasted pumping out the hole after it filled up. Working around the clock in two or three shifts is most efficient, since running the pump all night just to keep the water down is expensive. In addition, without an operator, the prime might be lost, allowing the pump to operate dry and perhaps burn out. To prevent the pump from pumping all the water out and losing its prime, the discharge is regulated by a valve or a section of fire hose which has been constricted with a valve.

The caisson cannot be driven ahead of the digging, but is kept as close behind the digging as possible to minimize the amount of material washed into the hole by hydraulic pressure. Moss and rags stuffed around the bottom help keep this outside material from entering. As the hole is deepened, more sections are added until bedrock is reached. The solid sections are removed by pulling with a chain hoist on a bridle attached at three or four points. If the shell is split, the bolts are turned so that the caissons can be taken apart or collapsed. As each section is removed, that part of the hole is allowed to slough.

The hoist used with caissons may be an ordinary windlass, but it is best to use a tripod which can be placed under the legs without disturbing them. A hand winch is bolted to a crosspiece between two of the legs, and the cable from this winch run through a snatchblock hanging from the tripod. The chain hoist used for pulling the caisson is hung in place of the snatchblock. Fig. 13-14 illustrates one type of caisson.

EVALUATING THE CAISSON HOLES - The total volume of material removed per interval of drive is rocked or sluiced, and the gold or other mineral recovered is weighed. For each foot of drive, a cubic foot of undisturbed gravel from the center of the hole is panned or rocked separately. This gravel cannot be salted by material rushing in from outside the hole. The volume which this cubic foot of gravel occupies loose is measured to determine the swell factor. By measuring the volume loose of the total material from each foot of drive, and decreasing that volume by applying the swell factor to get the volume in place, it can be determined whether much material is coming in from outside. If much material is entering, the value per cubic yard obtained from the hole will not be accurate. If the independent sample of a cubic foot of gravel in place is taken for each foot of drive, several determinations of the swell factor are obtained, providing a more accurate value.

The U. S. Smelting, Refining and Mining Company uses the following procedure in evaluating a caisson hole: several determinations of the swell factor are made by actually digging out a cubic foot of material in place and measuring the volume loose. For each interval of drive (intervals are greater in barren ground than in ground containing gold), the number of one-cubic-foot buckets of loose dirt hoisted is noted. The buckets are dumped directly into the dump box of a short sluice or long-tom to which water is pumped. The volume of undisturbed dirt removed from the drive is then computed by reducing the volume loose by the swell factor. If the volume arrived at in this way is greater than the volume obtained by multiplying the area of the caisson by the depth of drive, gravel is being forced in.

An example best illustrates the computation. Suppose that one cubic foot of gravel in place yields 1.3 cubic feet loose; the swell factor is 1.3.

$$\frac{1}{1.3} = 0.77 \text{ cu. feet in place for each cu. foot loose}$$

Now, assume a caisson of four foot diameter.

$$\text{Area} = (2)^2 \times (3.14) = 12.5 \text{ square feet.}$$

Further, assume a drive of 2.75 feet. The volume of dirt in place from the interval is:

$$\text{Volume} = (2.75) \times (12.5) = 34.6 \text{ cu. feet in place.}$$

Now suppose that in driving this 2.75 feet, 46 buckets (46 cubic feet loose) were hoisted and sluiced.

$$\text{Volume} = (46) \times (0.77) = 35.4 \text{ cu. feet in place.}$$

The amount of gravel that would have been hoisted, if none had been obtained from outside the caisson, would have been 34.6 cu. feet, but since 35.4 cu. feet were hoisted, 0.8 cu. foot came from outside the caisson.

To evaluate this 2.75 foot interval of drive, suppose that \$0.73 worth of gold is recovered.

$$\frac{0.73}{35.4} = 2.06\text{¢ per cu. foot}$$

$$(2.06\text{¢}) \times (27) = 56\text{¢ per cu. yard}$$

The volume used, 35.4 cu. feet, is obtained by reducing the measured volume loose to volume in place calculated from the caisson dimensions. The tenor of the ground for the whole shaft is obtained as for a shaft in frozen ground once the values per cubic yard for each section are known. If a large amount of water must be handled, the pump keeping the hole dry may remove an appreciable volume of sand. It may be necessary in such a case to allow this sand to settle in a tank, and to measure its volume and add it to the measured volume loose. Fig. 13-15 shows the arrangement of equipment used by the U. S. Smelting, Refining and Mining Company.

If much material is coming in from outside the caisson, the safest policy whenever possible is to take one cubic foot from the "island" in the center of the shaft for each foot of drive and to rock it separately. In ground with boulders this method may be impossible. If done, it gives a one square foot sample from the surface to bedrock which should be uncontaminated by outside material. If the tenor of the ground computed from the central material differs much from that computed from all the material, the results from the center portion should take precedence.

All data obtained from a caisson hole should be recorded; an ordinary drill log can be modified for this information. One method of keeping such a record is shown on the accompanying sample log. (Fig. 13-16).

This drill log has been altered to take the data obtained when sinking a caisson; each column is numbered. They are as follows: (1) the time of finishing each drive, (2) the depth of drive, (3) the diameter of the caisson, (4) the measured volume loose (in one cubic foot buckets), (5) the true volume loose, which is the measured volume plus the volume of sand brought up by the

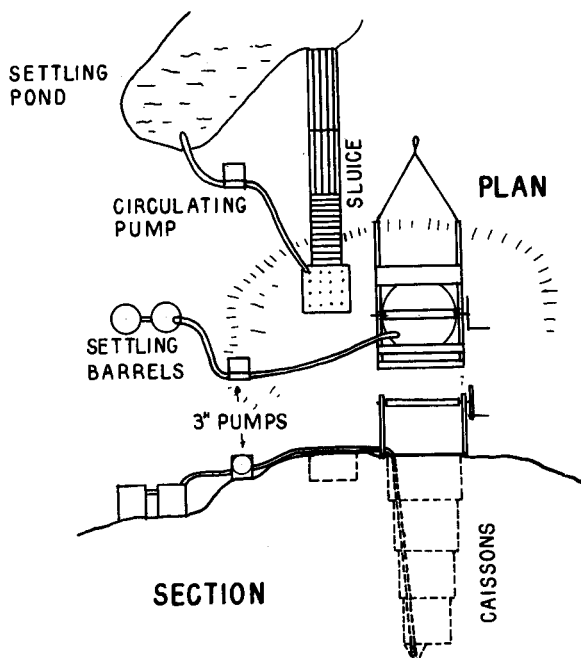


Fig. 13-15 - Arrangement of Caissons, Pumps, Sluice, and other Equipment. (U. S. S. R. & M. Co.)

CAISSON

FIELD LOG

FINISHED MOVING Sinking ELEVATION 2008 HOLE NO. 2 LINE NO. 1
 COMMENCED Sinking 7:15 AM June 8, 53 CO-ORDINATE CREEK Pho Lon
 FINISHED Sinking 3:30 AM June 11 CO-ORDINATE CLAIM 18 Below
 FINISHED PULLING WATER LEVEL WITH WITHOUT CASING

TIME OF PUMP	DEPTH OF PUMP OR CASING	CORE Before After	Measured Volume LOOSE	Volume	No. of Colors	Est. Value or Weight	Character Material Formation	Remarks	Column Feet	EST. No. EST. Col. WT.
		DATA								
								JUNE 8, 1953		
7:15	0	60"						TH. MUCK, 30MB SMALL SLIDE NEAR BOTTOM		
5:00	8-7	58 3/4"								
5:00	10-0	58 3/4"	28	28.25	23.0	-	-	NIGHT SHIFT TH. SAND & GRAVEL V. LT. FLOW 0.25 CU. FT. SAND FROM PUMP JUNE 9, 1953	1.42	1.75 1.23 -
5:00	11-3	51 1/2"	23	23.4	18.6	50	100	TH. SAND & GRAVEL LT. FLOW 0.4 CU. FT. SAND FROM PUMP NIGHT SHIFT	1.25	1.58 1.26 5 5
5:00	13-0	51 1/2"	32	32.8	27.5	75	250	TH. SAND & GRAVEL SOME SED. HEAVIER FLOW. 0.8 CU. FT. SAND FROM PUMP JUNE 10, 1953	1.75	2.09 1.19 8 10
5:00	14-8	51 1/2"	35	35.6	30.6	100	1500	TH. SAND, GRAVEL, AND CLAY. HARDER TOP BR. 0.4 CU. FT. SAND (PUMP) NIGHT SHIFT	1.67	1.93 1.16 30 50
5:00	16-0	47 1/2"	24	24.4	19.8	200	2000	SCIST BR. SOFT 0.4 CU. FT. FROM PUMP JUNE 11, 1953	1.33	1.64 1.23 50 100
5:00	17-6	47 1/2"	27	27.25	22.3	50	75	SCIST BR. - HARDER 0.25 CU. FT. SAND (PUMP) NIGHT SHIFT	1.50	1.83 1.22 9 10
3:30	18-9	47 1/2"	23	23.2	17.8	20	10	HARD SCIST BR	1.25	1.63 1.30 2 Tr
			FROM 1 SQ FT COLUMN							
			FROM 10	10	7					
			11-3	11.3	7					
			12-0	12.0	11					
			13-0	13.0	12					
			14-8	14.8	12					
			15-0	15.0	12					
			16-0	16.0	12					
			17-6	17.6	12					
			18-9	18.9	12					
ROCKER										
TOTALS			TOTAL COLUMN WT.	169						

REMARKS VOLUME LOOSE MEASUREDIN 1 CU. FT. BUCKET.PUMP: 150 CU. FT. MIN.GOLD, ACTUAL WEIGHT 3515 MGS.FROM 10 TO 11-3 82 MGS.FROM 11-3 TO 13-0 22 MGS.FROM 13-0 TO 14-8 172 MGS.FROM 14-8 TO 16-0 187 MGS.FROM 16-0 TO 17-6 40 MGS.FROM 17-6 TO 18-9 17 MGS.

TOTAL

MOSS _____ FT.

MUCK 8.6 FT.GRAVEL 6.1 FT.BEDROCK 4.1 FT.TOTAL 18.8 FT.

ABBREVIATIONS TO BE USED

Th.—Thawed Ice; Ice; V.—Very; St.—Sticky; Tr.—Trace;
 Fr.—Frozen; S.—Sand; M.—Muck; F. Gr.—Fine Gravel; B.—
 Boulder; Mk.—Muck; Ss.—Some; Md. Gr.—Medium Gravel;
 T.—Tailings; Cl.—Clay; L.—Loose; C. Gr.—Coarse Gravel;
 An.—Angular.

Time of Drilling _____ Hrs.
 Time of Pulling _____ Hrs.
 Time of Moving _____ Hrs.
 Time Lost _____ Hrs.
 Total Time _____ Hrs.

SHAFT J.D. R.R.

SWANES

Panners P.W. SH.Checked By G. J. H.

In Charge

Fig. 13-16 - Caisson Log Converted from Drill Log Form.

pump. By dividing this volume by the swell factor, the volume in place (6) is obtained. In this example a new swell factor for each drive is used; but often an average swell factor is used for each volume. In the next (7) is recorded the number of colors and, (8) panner's estimate of weight; then (9) formation (character of material), and finally (10) remarks.

The columns ordinarily used for water measurements are used to record data for a column one square foot in area from an island in the center of the caisson on each drive. As already noted, square foot sampling is not always done. When it is done, complete records should be kept as in the example. The volume in place (11) of this one square foot column for each drive is shown, and in the next column (12), the volume occupied loose by the same material. The loose volume divided by the volume in place gives (13), the swell factor for each drive, and this swell factor is used to determine the volume in place of the material from the rest of the shaft for that particular drive. Column (14) is the panner's estimate of number and (15) is the weight of the gold recovered. At the bottom of the log the true weights are recorded. The calculation follows:

From 10' - 0" to 17' - 6", 3498 mgs. of gold were recovered from the caisson, exclusive of the gold from the one square foot column taken from the center, which is computed separately. The lowest drive is not considered to be in the pay horizon, because it is likely that the insignificant amount of gold recovered from it came in with water from outside the caisson. The volume in place from which this 3498 mgs. came is the sum of the volumes from 10' - 0" to 17' - 6" or 118.8 cu. feet (adding column (6) from 10 feet to 17.5 feet). Assume 10 mgs. equal 1¢; then the average value per cu. yd. through the 7.5 feet of pay horizon is

$$\frac{(\text{value})(27)}{\text{volume cu. ft.}} = \frac{\$3.50 (27)}{118.8} = \$0.80 \text{ per cu. yd.}$$

The average value for the full depth is:

$$\frac{\$0.80 (7.5)}{17.5} = \$0.34 \text{ per cu. yd.}$$

It now remains to compare this figure with that obtained from the one square foot area in the center of the shaft. From 10 feet to 17.5 feet are 7.5 cu. ft. of material from which 169 mgs. of gold were recovered.

$$\frac{(16.9¢)(27)}{7.5} = \$0.61 \text{ per cu. yard.}$$

The average value for the full depth is:

$$\frac{\$0.61 (7.5)}{17.5} = \$0.26 \text{ per cu. yard.}$$

There is a discrepancy between \$0.26 per cu. yard and \$0.34 per cu. yard; which figure to use calls for judgment. Material entering the caisson under hydrostatic pressure from the sides consists mostly of fine material. If the gold works in with these fines, a disproportionately greater amount of gold will enter the caisson than the increased volume of gravel indicates. This condition can be determined by screening the sample from the center island and that from the whole shaft for each interval of drive. At one caisson driving job at a remote site, this screening was done with a one-eighth inch mesh galvanized screen. The result showed that there were four and a half times as great a volume of material smaller than one-eighth inch in diameter in the material removed from the whole shaft than in the island. Under such circumstances, the samples from the center island should be used if the results based on the center island are much different from those based on the whole shaft. If the tenor based upon material from the whole shaft were lower than that based on the center island, the lower figure should be accepted, because the higher figure is based upon a smaller volume, and could be accounted for by the inclusion of a nugget in the smaller sample. If the tenor based upon material from the whole shaft were much greater than that based on the center sample, however, as it is in this example, the evidence must be considered carefully. If the shaft penetrates relatively fine gravel, and the volume of material removed from the center island is carefully removed and measured, and is taken from a continuous column through the pay horizon, the figure based on that column should be accepted. If it is believed that the center island does not provide a representative sample, there is no alternative but to accept the tenor based upon the whole shaft.

Sinking Tightly Cribbed Holes

It is possible to crib down a hole in thawed ground if caissons are not available. As the shaft is deepened, logs are added at the bottom, pulled up tight with the windlass, and spiked and wedged into place. Moss is packed behind each log as it is added. The problems of sinking the hole and of evaluating the ground from the results are much the same as those encountered in

sinking caissons.

References

- Doheny, Larry, 1942, Placer Valuation and Dredge Screen Testing: Unpublished thesis, University of Alaska
Nordale, Arnold, 1935, Description of Fairbanks Prospect Drilling Methods: U.S.S.R. & M. Co. (Unpublished)

Chapter 14

DRILLING PLACER DEPOSITS

INTRODUCTION

The churn drill has supplanted all other methods of prospecting and exploring placer deposits on a large scale. Some of the advantages and disadvantages of prospecting and exploring with drills have already been discussed. As a general rule, whenever a placer deposit can possibly be sampled with small drill holes, the speed of drilling far outweighs any disadvantages accruing because of the small size of the sample.

It is difficult to say how much the speed of prospecting is increased by drilling rather than by shaft sinking, but ten times as fast is a conservative estimate. There are few places where the use of a drill cannot produce a rough estimate of how much gold is in the ground, these places being where the gold is extremely coarse and unevenly distributed. Even in these places, the drill can be used to find the channel and save perhaps months of blind shaft sinking. Whenever possible, therefore, the drill should be used; and when the prospector fully understands the shortcomings of drilling, the drill yields valuable information.

The reason more drills are not in operation is the high initial cost, both in equipment and in transportation, and the fact that the prospector cannot realize any returns in gold from his operation. When groundsluicing or sinking shafts, the prospector may turn miner if he finds pay, but the driller must content himself with knowing the gold is there, awaiting some form of mining. Moreover, to realize the full benefit from a drill, a small tractor usually must be provided to move it. This investment in drill, tractor, fuel, and the tools and parts is often greater than the independent prospector can afford. For this reason the drill usually is an exploration tool, brought into use by companies to explore creeks after the individual prospector has demonstrated that gold exists there.

There has grown up among some engineers and drillers the belief that the chief aim of drilling placer ground is to arrive at a figure indicating how much money can be produced from a certain block of ground drilled, and that the ultimate success of the drilling program is attained when mining shows that value to be the true one. (Placer exploration engineers say for this condition that $R/PV = 1$, where R is recovery and PV is prospect value). While the realization of this aim no doubt would be a source of much satisfaction to the driller and the engineer, the chief aims of drilling should be: (1) to determine whether the ground can be mined at a profit; (2) to determine the limits of the paystreak. Incidental information is obtained on depths, type of gravel, configuration of bedrock, distribution of permafrost, etc.

The satisfactory achievement of these goals depends on many factors. Some of these, such as coarseness and distribution of gold, the driller or engineer cannot control; for this reason it is doubly important the work which can be controlled be as accurate as possible. This work resolves itself into two problems: (1) to obtain accurate results from the individual drill holes, so that the amount of gold and the volume from which it comes are accurately known; (2) to compute from the drill hole data the distribution and amount of gold in a piece of ground. Certain types of ground can be drilled with more accurate results than other types. Data on depths and type of material usually are exact, but data on value may be accurate or inaccurate. The wise prospector considers that the value which he computes for a certain block of ground represents an order of magnitude rather than an exact figure. Experience with large drilling programs indicates that for a large number of creeks over a number of years, actual recovery approaches the valuation set on the ground from drill data, but that for any particular creek, or year, the two values vary widely. It is always, therefore, a good policy to have supporting data to check the drill results before much money is spent on a mining plant. The check may be an old drift, the approximate production of which is known, or it might be an open-cut or a few shafts.

Drilling is done in crosscuts as already described. At the start, one hundred foot intervals are left between holes in a crosscut. The interval may be decreased when drilling a creek containing a narrow paystreak. The distance between drill lines is also great at the start, although before the ground is mined, the creek may be drilled with lines as close as 400 feet apart, so that stripping can be done exactly over the paystreak. One danger encountered in determining the limits of pay is in not making them wide enough. If this happens, marginal ground which might be worked profitably if mined with the rest of the paystreak, may be covered with overburden during stripping, rendering it valueless.

EQUIPMENT

Power Churn Drills

Practically all placer drilling is done with churn drills, the same type developed for drilling water wells. In general, the placer churn drill consists of the following. A vertical derrick (or tripod) supports a pulley (crown sheave) through which a rope or cable passes. One end of the line is wound on a drum; the other end is fastened to the digging tools. Between the drum and the crown sheave is a mechanism for alternately pulling up and dropping the line with its attached tools, which imparts a churning (also called spudding) action. The churning motion causes the rope on the hoist drum to work and wear. To minimize this wear, old gunny-sacks or cloth strips may be worked into the strands of the rope. The drum which holds the drill line fitted with a brake strong enough not to slip even when the entire weight of the tools is bouncing on the end of the line. The drill is also equipped with a smaller drum, friction driven, upon which is wound the sand line, a small cable which lowers and raises the pump for cleaning cuttings from the hole.

Several makes of churn drills are on the market at present. When comparing the drills and their costs, the prospector should remember that he gets what he pays for. For example, a drill capable of driving four inch casing produces a sample less than half the area of one which drives a six inch casing. Likewise, the drilling capacity of the light drills is less than that of the heavier ones and more time must be spent repairing the cheaply built drill.

The Fairbanks drill, developed by Victor Spjelseth, a Fairbanks driller, is a medium sized drill used in many places in Alaska. A four cylinder LeRoi engine furnishes power which is transmitted by belt, clutch, and chain to a sprocket wheel mounted on a walking beam. On each end of the shaft to which the sprocket is fastened are cranks, the handles of which turn in bearings on the ends of pitman arms extending up from the frame. As the sprocket turns the shaft, the cranks turn, alternately raising the shaft and the walking beam above the pitman arms and dropping them below. A pulley is free to turn and slide on the shaft and the drill rope or cable passes under this pulley from a drum near the back to the crown sheave at the top of the derrick, thence down to the tools. The up and down motion of the pulley on the shaft imparts the churning motion to the line. A friction driven shaft contains the sand line drum.

This drill handles five or six inch casing and four inch diameter drill tools and has a capacity of about 175 feet with manila rope or 275 feet with wire line; one hundred feet of casing are pulled easily. The weight, less tools, is 2700 pounds; the approximate cost today is \$3000, including tools but no casing. The Fairbanks drill is well built, incorporating many of the best features of larger drills, and has a smooth action. Unfortunately, the Fairbanks Drill Company is no longer in business, and it may be impossible to obtain replacement parts.

The C. Kirk Hillman Airplane Drill (Seattle) is perhaps the lightest derrick drill built. This drill is simply made and light (1600 to 1800 pounds without tools), and drives a four or five inch casing. Power is supplied by a three HP or a five HP Fairbanks Morse engine. The practical drilling capacity is about forty feet, although open holes can be drilled deeper, but slowly. The churning, or spudding, motion is supplied by a pulley on the end of a revolving crank, which alternately tightens and loosens the drill line. This drill is gear connected with no clutches, but power can be applied gradually by lowering the engine onto V belts. It has a jerky motion, due to its lightness and the sacrificing of many refinements to the cause of saving weight and money, but it gets the holes down in shallow ground for less cost than almost any other drill, although yielding a smaller sample. The Airplane Drill costs about \$1700 to \$2000 (depending on engine size) exclusive of tools, FOB Seattle. Fig. 14-1 shows an Airplane Drill in operation.

The C. Kirk Hillman Company also builds larger drills, among them the Prospector which weighs about 4500 pounds exclusive of tools, and costs about \$4600 FOB Seattle. It is designed to handle six inch casing and is capable of drilling any placer ground found in Alaska. The spudding motion is supplied by a walking beam instead of a pulley on a crank, as on the Airplane drill.

The Keystone Driller Company developed the first churn drill in America and still holds a high place as a drill manufacturer. Their drills, being the first in the field, probably have drilled more ground in Alaska than the other types. The manufacturers of the Star Drill, similar to the Keystone, recently merged with Keystone, the new Company being known as the Star-drill Keystone Co. The earlier models were powered by steam engines, but almost all of these have been converted to gasoline or diesel. The earlier models also were quite heavy, but the company has lately developed smaller drills which still have the power to handle large casings in deep ground. Such a drill is the Model 70, having the following specifications: Weight, 6572 pounds without tools; tool weight, 1500 pounds (longest stroke) to 2250 pounds (shortest stroke); Motor, Waukesha twenty HP gasoline, or Hesselman diesel; derrick height, thirty four feet.

Another large drill, capable of drilling any ground in Alaska, is the Bucyrus. Several models are made; the 33-P prospect drill weighs about 6000 pounds and is powered by a twenty

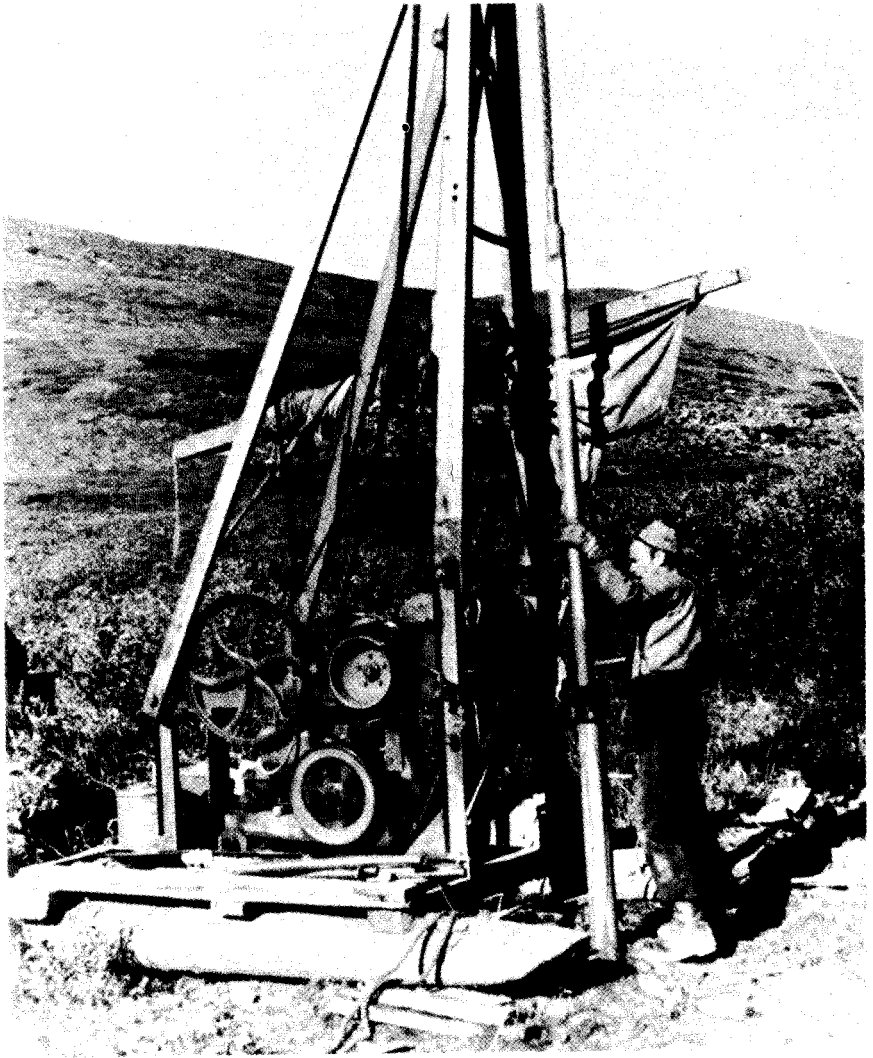


Fig. 14-1. - Small Placer Drill in Operation. Tarp Protects Panner When it Rains

or twenty five HP engine.

Other churn drills are manufactured, a few of which are working in Alaska, but the best known have been mentioned. If necessary, the prospector can improvise by using a standard string of tools on a rope which passes through a crown sheave on a tripod to a cat head on a small stationary engine. The driller alternately pulls on the rope, allowing the cat head to lift the tools, and slacks off, allowing them to drop.

Hand Drills

There are various hand drills which are very important in countries where labor is cheap, but which are unimportant in Alaska.

In the Empire Hand Drill, a steel platform is fastened to the top of the casing, which is fitted with a toothed cutting shoe. Men or horses turn the casing, and the weight of four

men on the platform causes it to sink. These men alternately lift and drop a string of jointed rods to which is attached any one of a number of bits, usually a combination pump and bit. The rotating toothed shoe cuts a core and the drilling pump cuts and removes it.

The drill weighs about 1000 pounds, exclusive of casing, and breaks down into seventy five pound pieces, which can be packed easily. The four inch casing weighs ten pounds per foot. Holes of 125 feet have been drilled with the Empire drill, but in rocky ground the capacity would be much less. The casing is removed by pulling with a pole lever and twisting at the same time.

Several other types of hand drills may be improvised. One, the spring pole drill, consists of a thirty foot pole, ten inches in diameter at the butt end and six inches at the top, anchored at the big end and leaned against a support so that its small end is over the hole. A string of jointed rods with a bit attached at the lower end is suspended from the pole with a rope. A cross handle near the top of the rods is worked up and down by two men, the whip of the pole storing much of the energy and helping on the lift stroke. A tripod, from which hangs a snatch block, is set over the hole, and a line is led through the block to a winch on the tripod. This rope is used for lifting the rods, pumping, and for applying a strain in pulling casing.

Another hand drill, which can be obtained from the Empire Company, consists of a tripod with a crown sheave at the top through which the drill rope passes. One end of the drill rope is attached to a standard string of tools and the other to a windlass drum which is attached to the tripod and can be braked to avoid rotation. A walking beam with handles long enough to accommodate four men on each side pivots on the windlass drum. The men alternately pull on the walking beam handles, lifting the tools and releasing the handles, allowing the tools to drop. Drilling, driving, and pulling casing proceed as with a power drill. In South America, these drills sometimes drive four inch casing to eighty feet and six inch casing to thirty feet.

The Acker Drill Company, Inc., of Scranton, Pennsylvania, manufactures a soil sampling kit. Although a chopping bit is supplied, this sampler is primarily an auger. To drill ground containing thawed gravel, it is necessary to drive light, small diameter casing, but shallow holes in frozen ground can be drilled open. As an auger, the kit has been used to sample placer beach sands in Alaska, holes thirty feet deep having been drilled.

Tools and Accessories: Assembling

The equipment which hangs upon the drill rope is known as the tools. From top to bottom, a string of tools ordinarily consists of the rope socket, the stem, and the bit. If extra weight is desired, a sinker bar or short length of stem is added. These tools are cylindrical and are of almost any diameter, two to four inches being most common. They are fastened together by pin and box (tapered male and female threaded parts, much stronger than ordinary threads). The rope socket is a short cylinder reamed out to the diameter of the rope or cable to which it is to be fastened. The stem is a long cylinder whose function is to add weight. The bit is a cylindrical piece flattened and sharpened at the lower end. The exact shape of the cutting edge and of the bit depends upon the type of ground that is to be drilled. Rock bits are heavy and thick, and their cutting edges form a relatively blunt angle. Placer bits, for chopping fine gravel, are thinner and have sharper cutting edges. The exact shape of the bit for fastest drilling in any particular ground must be determined by experience. Jars consist of a short stem constructed of two parts having a few inches of endwise motion. The set of jars goes above the stem, it would have little effect below the stem; because when the jars are slack, the weight above them is ineffective in adding anything to the blow of the bit upon the bottom. A sinker bar is used above the jars to provide weight for the upward stroke. Jars are used when there is danger of the bit sticking, as they provide an upward jar very effective in extracting a stuck bit. Jars are allowed to open only a little way. Fig. 14-2 shows a string of tools inside a casing.

All of these tools are round in cross section, except of course, the lower part of the bit. In order that the joints may be tightened with wrenches, a square section, called simply a square, is cut at each end of the stem and on each of the other parts. The wrenches used to tighten the string of tools are called drill tool wrenches, or stem wrenches, and are extremely sturdy. The string of tools is laid on low wooden blocks on the ground in front of the drill. (The rope socket must be pulled down with enough rope lying slack so that the socket can be turned freely). The pins and boxes are made absolutely clean by brushing with gasoline, if necessary, with both a wire brush and a bristle brush. The boxes must be examined closely to make sure they are clean. A small amount of oil is then put on each pin, and the joints screwed up by hand. The wooden blocks are put under the joints and the stem wrenches are put on the squares on each side of the joint, so that they tighten in the direction of the hooks. The end of one wrench is placed on a block on the ground and the other used to tighten the joint. When it cannot be tightened any more by hand, the chain wrench bar is used. This is a lever with a chain at the end and another chain a few inches from the end. The chains are caught in slots in the ends of the wrenches and the lever pulled to shorten the chain, tightening the wrenches and joints. All the pressure that one man can apply is used. When the joints are tight, a cold chis-

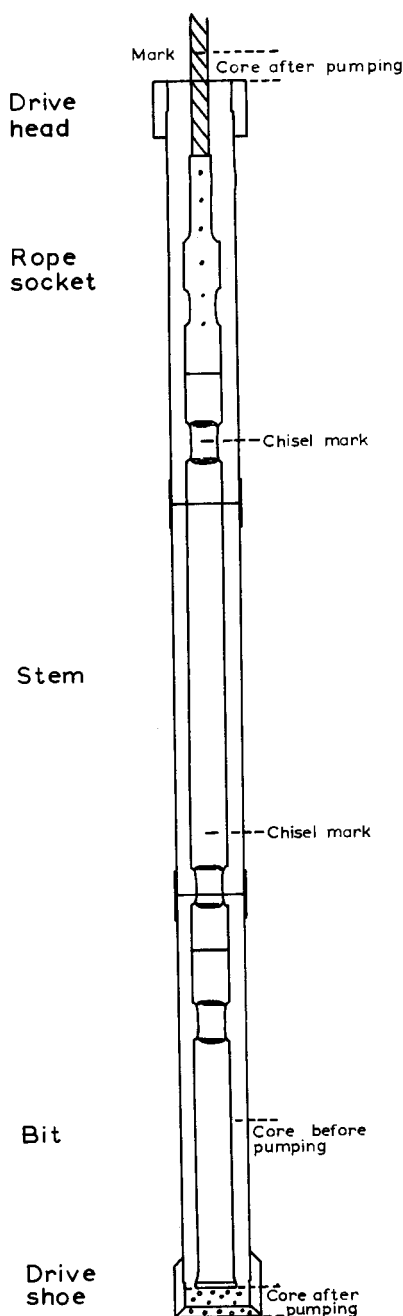


Fig. 14-2. String of tools, Showing Relationship Between Tools and Casing. Cores are measured by measuring from top of drive head to next mark.

el mark is put on each joint, and each time the joint is tightened, the marks should come to their original positions. Failing to come to the mark indicates dirt on the threads, and they should be cleaned. More than one bit will be used, the chisel mark on each being made to correspond with the one marked on the stem. Rubber thread protectors should be kept on all boxes and pins when they are not joined. Fig. 14-3 shows a string of tools being assembled.

If an old rope is in the socket and cannot be removed, the socket is heated in a forge or fire until the rope chars and falls out. The end of the new rope is wrapped to prevent fraying and is inserted into the rope socket almost to the threads. There are several holes in the rope socket, and a piece of sharpened rod of the same size as the holes is greased and driven through a hole, then cut off and driven through the next, and so on until all holes are filled. In this way only one point must be made on the rod. The rods in the rope socket are riveted slightly. The rope, being rigid on the up stroke, is subjected to harder wear against casing or gravel than on the down stroke. When the hand is rubbed up and down the rope, the rope feels rougher in one direction than the other. The rope is inserted correctly when this roughness is felt when running the hand upward. The nap, which is lying down when the smooth feel is produced, protects the rope on the up stroke.

Joining a wire rope to a rope socket is more difficult than joining a manilla rope. A swivel socket should be used except in an emergency; if no swivel socket is available, a method of joining a wire rope to an ordinary rope socket must be improvised. The swivel is a short sleeve which is joined to the end of the cable and which has too great a diameter to pull through the hole at the end of the rope socket.

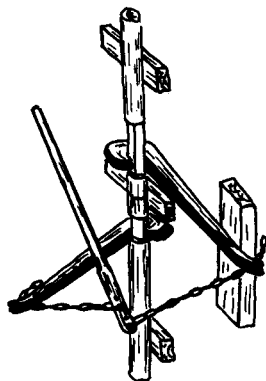


Fig. 14-3. Drill Tools Being Assembled.

To join the rope socket to the wire rope, the rope socket without the swivel is first slipped on to the rope and back far enough to be out of the way. Then the cable is wrapped with wire at a distance back from the end equal to the swivel length. The wires are unlaid and spread to form a rude broom, the exposed hemp is cut out, and all grease cleaned off the wires by dipping them in gasoline. In this cleaning and the one that follows, the rope is kept pointed down so that the cleaning agent does not run back into the wire rope, removing the protective grease or destroying the hemp. After the gasoline has evaporated, the wires are dipped in dilute hydrochloric (muriatic) acid for from thirty to sixty seconds, removed and dipped in boiling water, then allowed to dry in the air. At this stage, the wires must not be touched with anything but a perfectly clean cloth or clean gloves; grease or perspiration spoils the cleansing. Next, the wires are gathered with a temporary tie, and the swivel, which is also perfectly free of dirt or grease, is slipped onto the end until the end of the unlaid cable is flush with the lower end of the swivel. The top of the swivel is sealed with tape or clay, and zinc or babbitt is poured into the swivel, which is tapped to insure that all the spaces are filled. Enough metal is used to completely cover the unlaid wires.

The metal should be pure, or a weak joint results. Grease or dirt remaining on the wire or on the swivel causes air pockets and poor contacts, resulting in a weak connection. The presence of grease may be dangerous by causing the liquid metal to be blown back. A few sal ammoniac crystals put on the wires before pouring helps the metal to enter all the cracks.

The metal is at the correct temperature when a stick of wood can be inserted into it without having metal stick to it (indicating the metal is too cold) or being badly charred (indicating the metal is too hot). A slight discoloration of the stick indicates the correct temperature. If the atmospheric temperature is below 65° F, the swivel is pre-heated. Before the joint is poured, a single wire is passed through the metal. If this wire is not plated with a clean smooth coating, which adheres even when tapped, the wires are recleaned; and if recleaning does not remedy the trouble, clean metal must be obtained and the ladle heated red hot to remove the impurities.

After the metal has set, the bindings and sealer are removed, the socket slipped over the swivel, and it is ready to use.

The tools so far described are drilling tools. In thawed ground it is necessary to drive casing for which several additional tools are required. The driving head is a heavy piece, something like a coupling, which screws onto the top of the casing. It has a shoulder which seals against the top of the casing, thus preventing the threads from absorbing the blow. The drive clamps are two heavy pieces, which, when held together with bolts (drive clamp bolts), grip a square on the stem. As the tools work up and down, instead of going to the bottom of the hole as in drilling, the drive clamps strike the driving head with the full weight of the string of tools, thus driving the casing. Two special wrenches are furnished for turning the drive clamp bolts and nuts.

The casing itself is the finest obtainable, because it must be driven and pulled many times (fifty times a season is not unusual). Even when the strongest grade is used, pipe is sometimes pulled apart at the threads during unusually heavy pulling. Drill casing is known as extra heavy drive pipe and is normally used in five foot joints. Heavy couplings are used, and the threads are straight (untapered), so that the pipe butts in the center of the coupling.

The drive shoe screws onto the bottom of the pipe, and is left there, the same joint (the shoe joint) being used at the bottom each time. This shoe is somewhat like a thick coupling with a shoulder against which the pipe butts, removing the stress from the threads. The bottom of the shoe tapers so that the cutting edge is on the outside to allow the shoe to cut a hole of a larger diameter than the pipe. The shoe is hard and tough and seldom requires sharpening. The use of the Radford factor compensates for wear to some extent (see Calculating Drill Holes, page 249).

The casing is pulled with another set of tools. The bit is removed from the stem and a top puller substituted. This consists of a section of stem (called the pulling jars) with a large bulge on the bottom and a cap which screws onto the pipe and through which the pulling jars can slide. The bulge or hammer, on its upward stroke, strikes the bottom of the cap (knocking head) screwed on the top of the pipe. Being pulled in this way is the most severe service the pipe must undergo, because all the stress is taken by the threads. As the pipe emerges, the knocking head is uncoupled, the tools are lifted up out of the way, and the top joint of pipe removed; then the top puller is screwed to the next joint and the pulling resumed.

For very heavy pulling, a casing ring or bull ring is used. This is a ring which fits over the pipe and has two shoulders under which jacks can be placed. The ring is made to grip the pipe by means of toothed casing ring wedges or slips which wedge between the ring and the pipe. Under pressure they grip the pipe, but when the jacks are eased off, the ring and wedges drop down.

Ordinary pipe wrenches of the chain type (pipe tongs) are used for tightening pipe. Sometimes during extremely heavy pulling where the upward pull approaches the strength of the casing, the pulling is done from the bottom by putting a casing spear on the bottom of the string of tools. This tool engages the inside of the casing, near the bottom, with slip wedges, a set of jars giving it a bumping action during spudding. The casing spear is also used to pick up broken

casings. For very heavy pulling encountered in the Fairbanks district, a "camel hump" was devised. This is a pulley placed on the drill frame between the sheaves on the walking beam in such a position that when the walking beam is at the top of its stroke, the drill line just clears it. When the walking beam drops, the rope is humped over the extra pulley, greatly lengthening the stroke and thereby allowing a stronger blow to be delivered.

The material from the hole is removed with a sand pump, a cylinder with a flap valve in the bottom. A leather or rubber piston is attached through a rod to a cable, the sand line. As the sand line is hoisted, the piston moves up, drawing sludge into the pump. When the piston reaches the top of the cylinder, the rod picks up the whole pump, and as the material inside is kept from running out by the flap valve, the pump and its load are brought to the surface. A good pump is capable of picking up silver coins, shot, or other heavy objects, and some operators test their drillers and panners by dropping shot into the hole. The pump's load is dumped into a special dump box, a box with the bottom slanting toward a down spout at the lower end to allow the load to run to a volume bucket. The volume bucket has graduations on it, or a stick calibrated in tenths or hundredths of a cubic foot is used to measure the volume of material brought up. The volume bucket hangs from the dump box; a tub is placed under it for safety.

Special tools for recovering lost tools are called fishing tools and screw onto the stem in place of the bit. In general they are for jarring the tools when the drill line is still intact, or for spearing or snagging a broken line, or for clamping to the tools or casing. It is difficult to know how many fishing tools to keep on hand because each job might require a different tool. For this reason, most drillers keep none with them and depend on careful work and attention to the condition of the equipment to obviate fishing jobs. In shallow ground it is often cheaper to sink a shaft to recover tools than to keep a large supply of fishing tools on hand. One tool which might well be kept, however, is a jar bumper, a weight slotted so that it will slide on the drill line. If dirt sloughs in on the drill tools so that a straight pull will not extricate them or if the bit sticks, the jar bumper is fastened to the sand line and dropped down the drill line to bump the tools downward. Alternate bumping and hoisting is effective in freeing stuck tools. The use of jars in drilling sloughing or sticky ground usually prevents the tools from getting stuck. Sometimes, if the tools are stuck, they can be freed by putting a stress on the drill cable and hitting it with a sledge hammer or drill tool wrench. This blow puts a great pull on the tool.

The Stardrill-Keystone Company gives five rules to follow to keep from needing fishing tools:

1. Make sure the cable is in perfect condition.
2. Make sure the cable is securely fastened in the rope socket.
3. See that all joints on the drilling tools are set up firmly before going underground.
4. Use jars in sticky or sloughing ground, and examine the jars every time they are put on.

Tap with a hammer to detect cracks.

5. Protect the hole so far as possible with casing to prevent material from sloughing in.

A recent suggestion found in the literature states that a small amount of detergent in the drill water helps to disintegrate clay. As clay sometimes causes stuck tools, this procedure may eliminate some sticking.

As a blacksmith shop is not always accessible, a forge is supplied with a drill. A small blower, designed to be coupled to the drill engine by a belt, blows air through a tube (which can be made from an old inner tube) to a tuyere iron (see section on blacksmithing --Chapter 16). With the forge close by, bits need not be carried far and can be sharpened without much loss of time.

PROCESS OF DRILLING

The site for the first hole is chosen, and the drill hauled to the site by tractor, dogs, or under its own power. If no other means for moving the drill has been provided, a special capstan, called a cat head, is placed on a slow moving shaft (the spudding shaft on a Hillman airplane drill), and a rope or cable run out to a hook or anchor; it may be necessary to double or triple the line or to use rollers. Several turns are taken around the slowly turning cat head, and the cable is pulled tight. The friction between the drum and the cable causes the cable to be wound onto the cat head from the front and off from the back, pulling the drill along on its skids.

A bulldozer, if available, should level an area first; then the drill is leveled with levers, jacks and blocks. The drill is level when the tools hang so that the bit strikes the ground between the skids a few feet ahead of the derrick and exactly in the center. Very light drills should have bars driven alongside the skids to prevent them from creeping. Next, barrels of water are brought to the drill (the helper may have to carry this in five gallon buckets while the driller is busy servicing the drill, etc.). The casing, dump box, barrels, panning tubs, levers, chains, etc., have been brought to the site on a "go-devil" (a platform on skids) dragged behind the drill. The dump box is set six to ten feet in front of the drill, the tub put under the spout, and the panner arranges his tubs and barrels.

One barrel of water should be near to the driller for drill water and another to the panner

near the dump box. Two or three panning tubs are used— one for rough panning soon beaming muddy — and the others for successively fine panning. The water in the last panning tub must be kept clean so that the panner can see when he gets near the bottom of the pan. Excessive mudding of the first water can be avoided by putting water in the pan, stirring the contents and dumping the muddy water outside the tub. If this process is repeated two or three times, much of the fine mud is thrown out, leaving the panning water proportionately cleaner.

Water can be handled with dippers made from No. 10 cans. A slot is cut from the top down an inch or so, and a flap turned down so that it sticks out at right angles to the can. A stick eighteen inches long is put in the slot so that the end of the stick touches the inside rim of the can opposite the slot. The can is nailed to the end of the stick and at the flap, making a serviceable dipper. A nail is driven into the underside of the handle by which the dipper can hang on the edge of a barrel. Fig. 14-4 shows two dippers.

The smaller drills are operated by two men, a driller and a panner-helper. Larger drills require a driller, a panner, and a helper. The preliminary work is done by the whole crew and may be divided up as the crew wishes, but it should always be done in the same way each time; each man should have his own work, and each tool and piece of equipment should be kept in the same place. The driller, ordinarily, is in charge, but this authority may vary: the judgment of the most experienced man should prevail.

Cased Holes in Thawed Ground

The tools are joined together as already described, and the point where the bit touches the ground is determined. A slight depression is dug and the shoe joint placed in it. The drive cap is screwed onto the pipe; the tools are inserted into the casing and dropped to within three inches of the ground. After a little water is dumped into the pipe, the churning action is started slowly. If the ground contains no large rocks, the bit now drills a straight hole into which the casing drops. This starting a hole, or spudding in, is sometimes difficult if rocks are encountered, because the casing slides to one side or another, an action to be avoided if possible. If the position of the hole must be shifted, it necessitates shifting the drill, a laborious process when done by hand.

The most important rule of drilling with cable tools, as the tools of a churn drill are called, is: Always drill on the stretch of the line. The drill line is never run out until the tools —either the bit or the drive clamps— touch bottom, but the tools are stopped dangling two or three inches above the bottom. Only in this way can a straight hole be drilled, for if the tools are allowed to strike bottom, the line goes slack, and there is a moment when they are unsupported. They will lean to one side or another slightly and start off in some direction other than straight down. This drilling on the stretch (or on the spring of the shock absorbers under the crown sheave, if wire rope is used) also allows the strength of the blow to be regulated. The farther above the bottom the tools are suspended, the lighter the blow.

When the hole is started, most of the string of tools is above the ground. If the driller cannot guide them from the ground and keep them from swinging wildly, the helper may go up in the derrick to do it for him. This aid is usually not necessary, however, as the driller soon gets the feel of the tools. Sometimes the drill is equipped with a "dummy", a guide ring part way up the derrick, adjusted so that it is right over the hole, to keep the tools from getting out of control. As the bit chops the dirt to sludge, it is lowered by momentarily releasing the brake holding the drum upon which the drill line is wound. The driller, without stopping the spudding, drops the tools just enough to maintain the right amount of stretch in the line. As the tools rise and fall during drilling, the driller constantly turns them to produce a perfectly round hole. After the hole has been drilled to a depth so that a considerable amount of rope is out, the natural twist as the rope is stretched turns the bit. Even so, it is good practice for the driller to keep twisting on the stem or rope as the drilling progresses. "Rotate the tools" ranks with "Drill on the stretch of the line" as a driller's axiom. Enough water is added from time to time to insure that a sludge is maintained. If the chopped up material in the hole becomes too dry, the bottom of the hole is cushioned from the bit. Depending on the material, the bit advances from one half to six feet before the cuttings must be removed. To

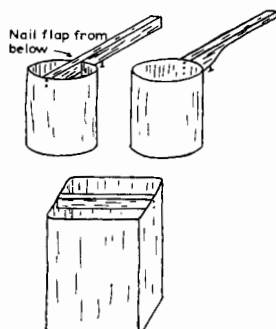


Fig. 14-4 - Water Dippers and Water Bucket Made from No. 10 cans and old gasoline can.

remove them, enough water is mixed with the cuttings to thin the sludge, the hoist drum is engaged, and the tools raised. All sludge is cleaned from the tools as they come out by pouring a small amount of water on them as they emerge. If clay clings to the bit, it is cleaned off with the fingers and thrown into the dump box. The string of tools is swung to one side and caught by a hook on the derrick, which keeps them out of the way. Fig. 14-5 shows a Fairbanks drill in operation.

The sand pump is now used to clean out the cuttings. The pump is dropped freely into the hole and allowed to sink into the sludge; as it strikes, the driller applies the broke so that the sand line does not unreel, snarl, and kink. The pump is hoisted rapidly until the piston reaches the top of the cylinder and the whole pump starts to rise. This one hoist may fill the pump, or two or three such hoists may be required. The pump is finally hoisted out, with the driller being on the alert to drop it back in case it is leaking. The helper grasps it and lays it in the dump box. The usual sand line control has three positions: pulled out is "hoist", pushed in is "brake", and in between is "free falling"; to drop the pump gradually, the driller allows it to fall an inch or so; then brakes it; then drops; then brakes, etc., until the pump is in the desired position.

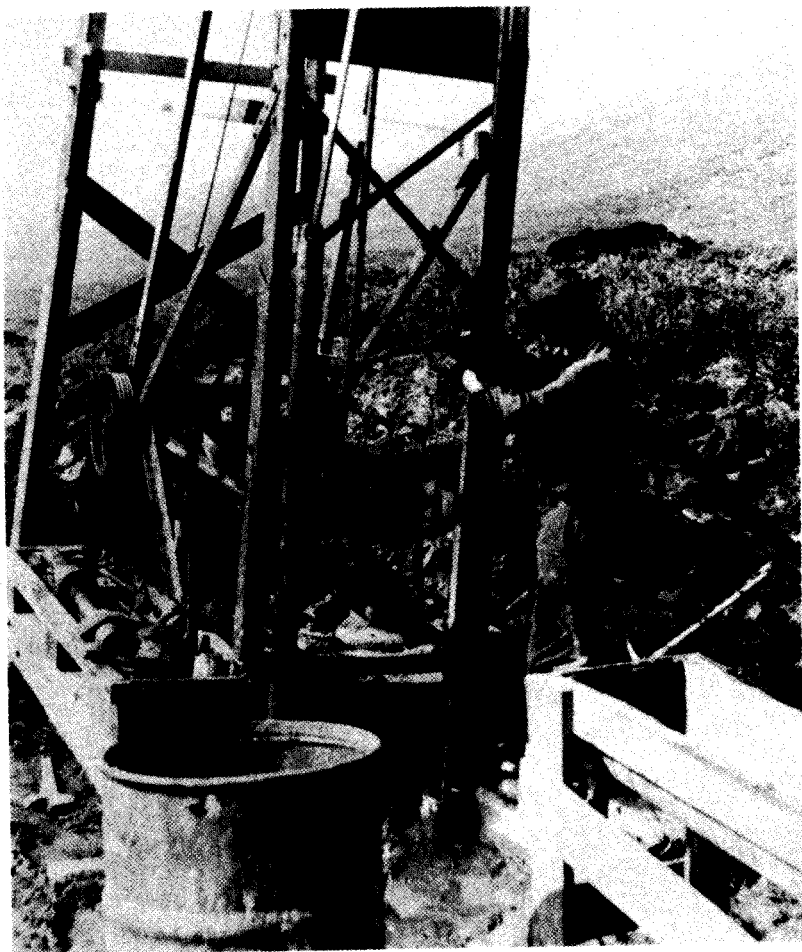


Fig. 14-5 - Fairbanks Drill in Operation. Top puller, drive blocks and accessory tools are laid on side of drill. Dump box and water barrel in foreground.

The dump box is in such a position that the drain spout is away from the drill. An adjustable rest at the lower end of the trough keeps the pump sloping down toward the upper end of the trough; a cradle made of iron rods keeps the lower end of the pump from resting in the trough. After the more liquid parts have run out into the trough, the panner or helper raises the adjustable rest to give more grade to the pump, then opens the flap valve with his fingers or the dipper handle and throws a small amount of water past the valve into the pump. He repeats this until the inside of the pump is clean, then cleans the outside of the pump and washes the material from the trough into the volume bucket. If the hole is not clean, it is pumped until it is.

In this description, the hole is just being started. In most holes this top material is discarded as barren. To speed up the pumping of barren material, a peg may be driven into the ground and the pump set upon it, so that the flap valve is opened and the material runs out.

After drilling two or three feet, the casing should start to fall; if it does not, it will be necessary to drive the pipe. The tools are dropped into the pipe until the first square is just above the driving head. The driller and his helper each take half a clamp and one bolt, and each pushes his half toward the other until the clamp is on the square. Each spins a nut onto a bolt and each picks up a wrench; with one holding and the other turning, they tighten the clamps with the bolts. The driller then drops the clamps onto the drive head to seat them against the upper edge of the square, and the clamps are tightened securely. The tools are raised until the clamps are a few inches above the drive head, and the spudding action is started. As the pipe is driven, it must be held perfectly plumb; if necessary, the whole crew helps to do this. Wedges may be driven into the ground alongside the pipe to guide it at the start; and when it is deeper, it may be necessary to pry with levers or even to use jacks to straighten it. Plumbness of the casing is determined by projecting the line of the tools hanging over the hole or sighting along the string of a hanging plumb bob. If the pipe is not driven straight down, the hole may have to be abandoned because the tools will jam during the spudding action. In extreme cases, the pipe cannot be pulled.

Even if the casing has been started plumb without trouble, the first driving cannot be carried far because the bit strikes material forced into the pipe. The clamps are dropped onto the drive head and unscrewed, each man taking one clamp, one bolt, and one nut, and placing them on his own side in such a way that the threads are protected from dirt and from contact with metal. Water is dropped into the hole and the core, as the material which pushes into the casing is called, is drilled, pumped out, and the pipe driven again. During driving, the pipe should be turned to make driving easier and to keep the joints tight.

When drilling the upper, barren ground, the driller does not worry whether he drills ahead of the casing; in fact he deliberately does so to speed the drilling. However, the recovery of gold requires other techniques. Before starting to drill, the exact length of the shoe joint, from bottom of the shoe to the top of the drive head, is measured and recorded; some drillers write this measurement on the drill. This distance is measured from the end of the bit upward and marked on the stem with a chisel. When the mark on the stem is even with the top of the drive head, the bit is at the bottom of the shoe. In drilling in thawed ground, the bit is never allowed to dig this far except when a boulder is encountered, in which case the bit must drill ahead of the casing a short distance so the casing can split the boulder and proceed. When it is necessary to drill ahead of the casing to break a rock, the driller should pour enough water into the casing to equalize the pressure inside and outside the pipe. This process slows the drilling but keeps hydrostatic pressure from the groundwater from forcing material into the casing. If the casing will not split the boulder, the rock is drilled into and the hole bailed dry. A stick of dynamite with a waterproof fuse is lowered into the rock and covered with dry sand for stemming. The driller must make sure the casing is well above the blast.

The solid material left protruding into the bottom of the casing, never less than two inches, is called the plug. The plug keeps hydrostatic pressure from pushing material into the hole and keeps material from being forced out of the hole.

When the first joint has been driven almost completely into the ground, the drive head is removed and a second joint is screwed on and tightened. The threads of the pipe and couplings are cleaned each time, but no oil is put on them, as oil in the hole might cause fine gold to float away. If the presence of oil is suspected or if oil from vegetation is encountered, a small amount of lye is thrown into the hole to counteract it. The drive head is replaced on the top of the pipe, and a mark is placed on the stem or rope five feet above the first mark. Marks may be made on the rope by weaving marlin into the strands. All joints are measured to make sure they are five feet long; if they differ, then, of course, the distance to the second mark differs accordingly. When the second mark is level with the top of the drive head, the bit is again at the bottom of the shoe.

Marks are made on the outside of the casing with colored lumberman's crayon at each foot starting from the bottom. These marks give the depth of the casing in the ground; the marks on the drill tools and rope show how near the bit is to the bottom of the casing. Fig. 14-2 shows the relation of tools to casing.

When the driller believes that he should start sampling the hole - and this should be well above any suspected pay horizon - he cleans out the hole, then drives the casing one foot (or two) to an even foot mark. He lowers the tools until they just touch the bottom, and measures

the distance from the top of the drive cap to the mark on the drill line (or stem). This is the core before pumping and it is called to the panner who records it. This core rise is a measure of the amount of material which has been taken in by the casing. As already stated, the shoe flares out, and the area covered by the shoe is greater than the inside area of the pipe. For this reason, if all goes well, the core rise within the pipe is greater than the distance driven. If the material does not expand and none is pushed ahead, the ratio of the core rise to the drive is the same as the ratio of the area of the shoe to the area of the inside of the pipe; and a theoretical core rise can be determined for a foot of drive. Of course, the material, as it rises, expands somewhat, giving a core rise greater than the theoretical, and as the pipe is driven, some material is pushed aside, giving a smaller core rise. If short (one foot) drives are made, less material is pushed aside than if longer drives are made. For average gravel, a core rise of seventy percent to ninety percent of theoretical rise is usual. Striking of a boulder by the casing or pushing rocks ahead and out of the way are the chief causes of short cores; hydrostatic pressure pushing in the plug is the chief cause of excessive core. In deep ground this hydrostatic pressure becomes so great that it is necessary to maintain water in the casing at all times to overcome it. This necessitates drilling and pumping under water, sometimes as much as two hundred feet in depth. The level in the casing is maintained as close to the natural water table as possible. The opposite effect - that of the casing acting as a pile and pushing most of the material ahead and aside - is likely to influence the results when drilling old tailings. These, near the surface, are so loose that it is difficult to get cores. Short drives should be taken, but the trouble cannot be overcome entirely. Usually knowledge of the old operation furnishes the best information on the value of such tailings. Drill sampling of tailings is only done for large operations.

After the core before pumping is recorded, the core is drilled to within two to four inches of the bottom of the shoe, pumped, and the core after pumping measured and recorded. If there is no core after pumping, or if the bit drops below the bottom of the shoe, an error has been committed, which, if it happens in the pay horizon, may introduce inaccuracies into the prospecting.

If the core is normal for the area being drilled, which as stated, is about seventy to ninety percent of the theoretical rise, the amount of gold taken from that core will be accepted as correct. If, however, the core rise was abnormally large or small, it must be corrected, as will be explained when the computation of drill hole values is described.

The panner, who should wear rubber gloves for protection, takes the sample after it has been washed from the pump into the volume bucket and "slimes" it by paddling and washing until only solids - fine sand to gravel sized material - are left. This sliming is done in the same way each time, so that the cleaned, slimed residue will give a comparison of the volume of material removed from the hole on each drive. This volume provides an added check on the drilling (in addition to the core rise). In loose ground it often happens that the pump actually drills ahead, without the material being first chopped up by the bit. An abnormally large or small volume obtained from a drive, without the character of the gravel changing, should be compensated for in the calculations by decreasing or increasing the amount of gold recovered.

After cleaning the material in the volume bucket and recording the volume in cubic feet, the panner transfers it to a pan under water in a shallow tub. The volume bucket is swirled by twisting the bucket rapidly in one direction and then the other to loosen the dirt which is then poured into the pan, or several pans if a large sample is obtained. The bucket is held slanting down toward the pan, with the lip under water, and a little water is splashed up into it. This splashing washes loose material left in the bucket into the pan.

The panning is done in a tub in which another pan - a "reject" pan - is submerged, and the material in this reject pan may be panned again if it is suspected that gold was lost. Some panners rock up all rejects when the hole is finished. These precautions are justified when it is remembered that the amount of gold in a drill sample is very small. The loss of a tiny bit of it affects the sample proportionately more than the loss of a bit from a pan taken, for instance, from bedrock in a shaft. For this reason the panning should be done very carefully. Examples are known of old prospectors, accustomed to panning in drifts or shafts, throwing away the sample from a foot of drive in a drill hole because they considered it insignificant. All gold from the drill hole is saved.

Panning is speeded up by using a grizzly pan with quarter inch holes above the main pan to remove the rocks and pebbles and to allow the gold to pass through with the sand. If, as would be very rare, a nugget is picked up by the drill, inspection of the grizzly will reveal it. After panning, the panner estimates or counts the number of colors, estimates the weight of the gold in milligrams, and records these figures. Some panners break down their count of colors into three classifications corresponding to three weight groupings. The panner also examines the material from the hole and records the type and amount of rocks and concentrate minerals. He also records anything of interest under "remarks". Any gold recovered is kept under water in a glass jar. It is a source of pride to many panners that they can estimate weights correctly. Experience shows, however, that when dealing with small amounts of gold, most panners not only cannot estimate correctly but not even consistently. The panner should strive, not so

much to estimate weights correctly, but to be consistent in his error. When the sample is all in one bottle, it is the panner's estimate alone which indicates at what level most of the gold was recovered.

The driller keeps driving, drilling, and pumping, adding new casing when necessary, and putting new marks on the drill rope so he can tell when he is near the bottom of the shoe. In the pay horizon or "in the money", he takes short drives, not more than one foot, to be assured of obtaining a good core. The hole is continued into bedrock until no more gold is recovered; and occasionally a hole is drilled ten feet or so into bedrock to be sure that what is thought to be bedrock is not actually slide. This deep drilling into bedrock should be done with an open hole, ahead of the casing, as driving and pulling casing in solid bedrock is slow work.

If the hole must be left overnight and there is any danger of some unscrupulous person salting the hole with gold, a measured portion of barren sand or muck is dropped in before quitting time. This is called the blanket. If any gold is found in it when pumped out the next day, salting is indicated. Another way to prevent tampering with the hole is to put a metal cap or tub over the casing and to lower the tools onto it. In this way no one can get at the hole without starting the drill. If a tub is used, a plank should protect it from the bit. This cap is called a night cap.

After the driller and panner are satisfied that they are through the pay horizon, or that no chance of finding pay exists, the bit is removed, and the top puller screwed to the stem. It may save time to loosen the stem, bit, and rope socket from each other while the tools are still hanging. Then they may be uncoupled by hand on the ground. The top puller is screwed on loosely, the tools dropped a short distance into the hole, the knocking head screwed onto the pipe, and the tools tightened with the chain wrench bar.

The driller adjusts the tools until the hammer on the pulling jars is two to four inches below the knocking head, then starts the spudding action. The hammer is thrown against the knocking head, driving the pipe upward. In tight ground it may be necessary to put the drive clamps on the square of the pulling jars so the pipe can be pounded down, then up, a process sometimes very effective. If necessary, the pipe pulling ring and jack may be used; turning the pipe with the pipe tongs may also help. As the pipe comes up, the drill line is shortened by taking up on the hoist drum. If the casing tends to drop down between blows, a block and falls may be rigged from the derrick to retain the gain made by the top puller, or the helper can hold a chain wrench on the pipe so that the pipe cannot slip back.

When the pipe is out of the hole, the top puller is removed from the stem and the bit is replaced. The tools and equipment are collected, placed on the sides of the drill or on the go-devil, and the drill moved to the next drilling site. For each hole, the panner prepares a marking post about three or four inches thick and five feet high, on which is carved the line and hole number. A cross piece is nailed about one foot from the bottom to keep the post from dropping into the hole when first inserted.

As each line of holes is completed, the elevation of each hole is determined by leveling from the last one, and each hole is plotted on a map.

Open Holes in Frozen Ground

Although the hole in frozen ground may be cased as is the hole in thawed ground, it is very difficult to drive and pull casing in frost. For this reason, frozen ground is almost always sampled with open holes. Usually at the surface is a thawed layer which must be cased to keep out water and debris. The shoe joint is driven to frozen ground, and the bit is used to drill ahead. The casing is driven into the frost until all surface seepage is excluded. This can be determined by reflecting sunlight (or a flashlight) down the hole and observing the bottom for a few minutes.

From here on, the hole is dug by the bit and pump. Marks are put on the stem and drill line in such a way that when any particular mark is level with the top of the casing, the bit is a known number of feet underground. Since in an open hole a smaller sample is obtained for each foot of drive than in a cased hole, two foot drives are made if possible. Constantly turning the stem or rope, the driller feels the bottom of the hole. Just enough water to keep the sludge from breaking the force of the blow is added. Cold water must be used and should be poured down the drill line to keep the walls from washing down; lowering water in the pump is even better practice. If ice and snow are available, they should be used in preference to water. As the tools are turned, if the bit sticks, it means the diameter is too small, and the driller concentrates on that place until the hole again is round. When the tools are hoisted from the hole, they are kept out for as short a period as possible so they will not warm up more than necessary. In drilling in muck, the included ground ice is chopped up and surges up with the bit on its upstroke. This ice is plastered against the sides by the flare of the bit and freezes there, allowing the stem to pass but not the bit when the tools are raised. As there is no gold in muck, anyway, the accuracy of the work is not affected by washing down the walls; and the use of hot drill water to melt the floating ice obviates this trouble. When gravel is reached, of course, no more hot water should be used; however, ice is seldom encountered in gravel.

The bits must be kept sharp to drill frozen ground, and if it is necessary to change bits during the process of drilling, great care must be taken to have the new bit sharpened no wider

than the old one. If it is wider, of course, it will stick. A sharp bit drills a hole slightly larger than itself; a dull one only as large as itself. It is good practice to keep a bit measure (a ring of the correct diameter which slips over the bit) on hand to check the gauge of the bit at least every ten feet. As soon as it wears appreciably, it should be changed.

Two of the most serious problems in drilling frozen ground are thawing of ground above, with consequent sloughing to the bottom, and freezing of water to the sides, with consequent sticking of the tools. When possible, a hole should be started and finished in one day with one bit; but if it is necessary to stop drilling for the night, the hole should be capped with moss to minimize thawing. The tools should never be left in the hole overnight (this precaution applies to cased holes also).

When drilling in the pay horizon in frozen ground, the driller keeps the gold in several samples, each one representing say four, six, eight, or ten feet of hole, depending on the values. Then, if water measurements show that a certain section of the hole has sloughed, it is easy to adjust the values when several samples were taken. It is, in fact, a good rule to follow whether drilling frozen ground or thawed ground, to start a new sample whenever anything unusual, such as recovery of an abnormal core or volume occurs. If an error is introduced by the unusual occurrence, the starting of a new sample confines the error to the old sample.

WATER MEASUREMENTS - Since the frozen hole has no constant diameter, as has the cased hole, its volume must be measured by a water measurement. The equipment needed is a hose at least as long as the hole is deep, a funnel which can be fitted into the end of the hose, a dipper which will hold a known volume of water (calibrated in parts of a cubic foot), and a measuring tape to which a small float is tied at the bottom end. This float should be weighted in such a manner that it will float, yet keep the tape stretched tight. It should be attached to the tape so that the surface of the water in which it is floating is at the zero mark on the tape.

As soon as the hole is finished, enough water is let down to cover the bottom, the float and tape are lowered, and the depth and time noted and recorded. Ten minutes later the tape is read and the figure recorded to indicate if there is any seepage into the hole, and if so, the rate. A well sealed hole has no seepage from the top but may have some seepage from lower down.

The tape is pulled up, the hose lowered to the bottom, and a known volume of water poured in. This volume depends upon the size of the hole, which in turn depends on the size of bit used. The hole made with a three and a half inch bit requires about one tenth of a cubic foot each time; that made with a five and a half inch bit about one quarter of a cubic foot. A tank, fitted with a valve to which is attached the hose, sometimes supplies the water for the water measurements. Volumes are then determined by reading a calibrated stick which is attached to a float in the tank. The tape is again lowered, read, and the reading recorded, along with the time. The process is repeated until the water level is well above the pay horizon. The pours are timed so that they come at equal intervals, but the work should be done as fast as possible. At the end of the measurement, another ten minute seepage measurement is taken. If seepage is coming in from a lower level, its rate may be affected by the height of the water in the hole. For this reason it is well to take a ten minute seepage measurement at the halfway mark if the pay horizon is very thick; ordinary pay horizons with thicknesses of from four to eight feet can be measured so quickly that this measurement is not necessary. The end of the hose during pouring should be just above the water level in the hole to prevent washing down the walls.

Sometimes in ground which has been drifted, a cavity is encountered. If it can be filled with water, the water measurements can proceed; if not, the only solution is to abandon the water measurement and to assume that the diameter of the hole above the cavity is equal to that of the bit plus a half inch or so.

When the water measurement is completed, any casing which is in the top part of the hole is pulled and preparations are made to move the drill.

Holes Partly Thawed and Partly Frozen

The most difficult ground to prospect is that which is partly thawed and partly frozen. If the thawed part is on top, of course, the casing is driven until the water is sealed off. If it is below the ground, it is necessary to drive casing through the frost. This makes for hard driving, and difficulty will be experienced in pulling the casing, but is the only way to sample bed rock. When the pulling commences, it is good practice to have hot water or steam available should the casing be frozen to the walls.

In the Fairbanks district, where muck of great thickness overlies the gravel, even where the gravel is thawed, the overlying muck is frozen and a special technique has been developed to get the casing through the muck. A hole is drilled with a larger bit, and hot water is used to sluice down the walls. When thawed ground is struck, a platform is built around the hole, and adjustable casing clamps to grip the pipe are mounted on the platform. The shoe joint is gripped in the clamps, the next joint screwed on, the clamps loosened, and the two joints lowered with the sand line or some auxiliary line. This process is repeated until the shoe binds in the hole, when the clamp is loosened just enough to let the casing slide, yet catch the next coupling

should it drop. The casing is then driven lightly. When thawed ground is reached, the hole is drilled as a regular cased hole.

Cold Weather Problems

If drilling is to proceed in cold weather, special equipment must be used. A panning tent, with a stove, which will house the panning tubs and dump box, should be provided. The C. Kirk Hillman Company sells a drill tent to cover the drill and driller for its airplane drill and for the larger "prospector" drill.

Since water has to be heated in cold weather, an efficient method must be devised. A simple water heater is made of two oil drums as shown in Fig. 14-6. A wood fire is built in the lower drum, and the flames and smoke escape between the flaps of the lower drum and the upper drum containing the water. This arrangement utilizes more of the heat than does an ordinary stove and insures plenty of hot water at all times.

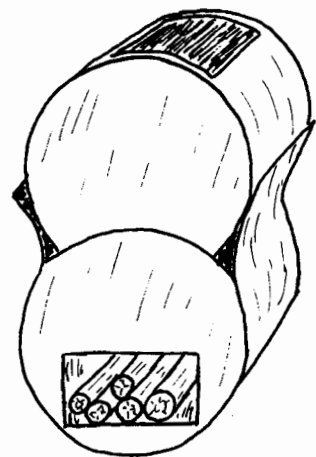


Fig. 14-6 - Oil Drum Water Heater

KEEPING RECORDS AND HANDLING SAMPLES

In drilling, all measurements are recorded. While the prospector may keep notes in whatever form he desires, it is usually best to use drill log blanks, which are available from publishers in Fairbanks. All the information required to completely describe a drill hole can be tabulated on these forms. Records are always kept in pencil, a 2H or 3H drawing pencil, never in ink. Ink disappears if the log gets wet. These logs have spaces for all pertinent information including time, location, equipment used, drillers, panners, etc. The drill data themselves are recorded in several columns, headed (1) Time of Pumping (little used) (2) Depth of Pumping or Casing (3) Core; before and after pumping (4) Measured volume loose (5) Theoretical Volume (not used in the field) (6) Number of Colors (7) Estimated weight of gold (8) Character of material in formation (9) Remarks, and (10) Water measurements; including Depth, from and to, Volume in cubic feet, and Time. The volume of water recorded is the total volume in the hole to that point. The "from" level is the starting level; each succeeding level is recorded under "to". Water measurement notes are started at the bottom of the sheet so that the position from which data came can be visualized easier. There is also a space for the actual weight of the gold, found by weighing afterward.

Each night the panner takes his sample bottle to camp, and either he, or someone designated, prepares the sample for weighing. The sample is panned down until it is as clean as it can be made; it then may be dried and cleaned with a magnet and by blowing, or if the gold is coarse enough, it may be picked out with tweezers. Usually, however, it is amalgamated with a small amount of mercury in the pan to which has been added a drop or two of nitric acid to promote amalgamation. The globule of mercury and amalgam obtained is transferred to a test tube. The amalgam is covered with dilute nitric acid and gently heated until the mercury is dissolved. The remaining gold is transferred to a porcelain parting cup (a tiny crucible used in assaying), washed, heated to dry, and weighed. The actual weight is recorded on the drill log. The gold sample is then transferred to a sample bottle about a half inch across and three inches high, to which is attached a gummed label. The hole number, line number, creek, date, and weight are written on the label, and the sample is filed away. When dissolving the mercury, the panner should not leave the gold in the acid after the mercury has completely dissolved as some silver might be dissolved, diminishing the weight.

CALCULATING DRILL HOLES

Everyone agrees that, except under unusually fortunate conditions, the amount of gold per cubic yard computed from drill hole data does not strictly represent the true tenor of the ground at any particular point. Everyone is not agreed, however, on what to do about it. In any discussion of the subject, the nature of placer drilling must be considered. At best, the conditions under which drilling is done are such as to promote inaccuracies. Differences in the material encountered by the casing cause more or less core to be obtained; differences in the temperatures of frozen ground cause more or less sloughing. These differences should be compensated, when possible, but it should also be remembered that it does no good to apply correction of, for instance,

ten percent when the method of obtaining the data being corrected is inherently inaccurate by more than ten percent. This is not to say that in any particular hole the drill is incapable of extracting an amount of gold which is within ten percent of the correct amount. (The "correct" amount is that amount which would be obtained if there were available some method of extracting an exact cylinder of gravel of the same diameter as the shoe, neither pushing dirt aside nor having it forced in under pressure). Under certain ideal sampling conditions - uniform pay gravel of just the right size and tightness - remarkably accurate results are obtained by the drill. However, under average conditions, it is improbable that any particular block of ground can be evaluated exactly by sampling with drill holes. Experience at Fairbanks by the United States Smelting, Refining and Mining Co. indicates that for the whole district the recovery and the prospect value agree remarkably well, but that for any one year or any one claim, there may be variations - as much as several hundred percent.

This close agreement of prospect value to recovery for whole districts leads many prospectors to believe that the drill is a very accurate prospecting device. Yet, how many prospectors have a whole district to drill? In spite of the accurate average at Fairbanks, there were large overruns and large underruns, and the prospector should remember that a section of a creek may have either. It should also be remembered that the accurate overall results may be due in part to the fact that the gold in Fairbanks district is fairly evenly distributed. It is probable that in a district like the Koyukuk district, where the gold is coarse and unevenly distributed, such accurate results could not be obtained, even if the entire district were drilled. The methods of calculating drill holes and of evaluating ground used by the United States Smelting Refining and Mining Co. evolved over a period of thirty years are given below. They are simple and straight-forward.

Thawed Holes

The four sizes of drill casing commonly used are four inch, five inch, six inch, and eight inch. The six inch pipe is used in this example. The exact dimensions of these pipes and their respective drive shoes are found in Appendix II.

A "six inch" casing has an inside diameter of 5.761 inches and an area of 0.181 square feet. Its drive shoe has an outside diameter of seven and a half inches and an area of 0.307 square feet. For every one foot of drive, if all the material encountered by the seven and a half inch shoe is forced into the pipe, the core should rise 20.3 inches, and should contain 0.307 cubic feet of material. (Some of the reasons why these theoretical values, 20.3 inches and 0.307 cubic feet are seldom obtained have already been discussed).

What must be determined is the casing factor, or the volume of material in place that enters the casing for each foot of drive. As each foot of drive is affected by slightly different conditions, no two drives pick up exactly the same volume of material. Almost every engineer has his own method of dealing with this situation. Some, for every foot of drive of a seven and a half inch shoe, want 20.3 inches of core; and if they get more or less, they will adjust the amount of gold from that drive to what it should be for 20.3 inches of core. For instance, if a fifteen inch core rise is obtained and ten milligrams of gold recovered, $\frac{(20.3)(10)}{15} = 13.5$ mgs. of gold is the correct adjusted amount for that foot of drive.

Another group says that instead of an area of 0.307 square feet for the shoe, an area of 0.27 square feet will be taken. This area, called the "Radford Factor", is the area of a circle seven inches in diameter and has been found to give better results than 0.307 under certain conditions. Since these conditions may not correspond to those found in Alaska, its adoption is purely arbitrary. The theoretical core rise using a casing factor of 0.27 is 17.9 inches, so the group which advocates its use adjusts all core rises to 17.9 inches. The use of the Radford factor with the seven and a half inch diameter shoe simplifies calculations, because one foot of drive contains a volume of 0.01 cu. ft. Radford factors for other size drive shoes are found by taking 88% of the actual areas.

Still another method is to find a ratio between the volume of solids left in the volume bucket and the actual volume in place from which that volume of loose, slimed solids came. With such a ratio, the engineer can say that the gold panned from a certain volume of loose material came from a certain volume in place. The most applicable method of arriving at this solids factor is to determine it for a hole in frozen ground, the volume of which can be determined by water measurements, and then apply it to a nearby hole in thawed ground. There are several variables which influence the choice of a solids factor, one being that different materials have different factors. Muck has no solids (clay and silt being slimed off) decomposed bedrock very few; but sand, gravel and solid bedrock have a large proportion. Also, the determination of the volume in the frozen material from which the solids factor is calculated may be in error due to sloughing or icing. Another factor to be considered is that the churning of the drill tools actually creates more fines than are naturally in the ground. Creeks are also known where the solids factor varies within a few feet.

These considerations, plus the realization of the inherent inaccuracy of evaluating ground

from relatively few very small samples such as are obtained from drill holes, have led many engineers to reduce drill hole corrections and adjustments to a minimum.

The method used by these engineers is about as follows. The average core rise for the hole is noted from the log; this rise usually varies between fifteen and nineteen inches with the largest number about seventeen inches. This core rise is what would be expected using a casing factor of 0.27 (0.27 square feet of area, or 0.27 cubic feet of volume for each foot of drive). But, instead of assuming that an average core of seventeen inches contains 0.27 cubic feet, this average core is still assumed to contain 0.307 cubic feet, just as if all the material cut by the outside of the shoe were contained in the seventeen inch core. This assumption, both theoretically and from actual observation, leads to a prospect value less than the actual value. Further, an abnormally short core, say, one of twelve inches, is not usually corrected, although one of eight inches probably would be, if it occurred in the pay horizon. (Doubling the amount of gold would be about the correct adjustment for this drive). Excessive cores, on the other hand, of greater than twenty inches, are corrected by scaling down the amount of gold in the sample. It will be remembered that it is considered good practice by the drill crew to begin keeping a new sample whenever such an abnormal core is obtained; this limits the effects of the correction to only a part of the hole.

This leaning toward the conservative side in deciding whether or not to apply corrections at least enables the engineer to say, "This is the minimum value at that point". The engineer's biggest source of confidence, however, is the ability and judgment of the drill crew. If the work is carefully done, the results usually require few corrections.

The volume of cleaned loose solids is also examined for abnormally high or low values. An excessive volume with no apparent explanation must be assumed to be due to the pump picking up material coming into the casing in addition to that found in the core, and the amount of gold recovered, if any, should be adjusted downward. If the drill crew is alert and knows its job, the next drive is made with more water in the hole to equalize the hydrostatic pressure which caused the excessive pumping, or a larger plug is left in the casing.

The adjustments to be made to the values of a drill hole because of an abnormal core or volume are to a considerable extent up to the individual and are based on his judgment and knowledge of conditions. As a general rule, adjustments are not made unless they will have an appreciable effect upon the value of the hole.

The best way to show a typical calculation is to start with an actual drill log. In the sample log, Fig. 14-7, it is seen that the values occur from eleven feet through twenty feet, the pay horizon; the prospector is not concerned with correcting any cores but those occurring in that interval. The cores range from fifteen to eighteen inches, with small plugs. First, it is noticed that in the drive from eleven to twelve feet, the bit got ahead of the casing (a minus core after pump). An examination of the volume, 0.160 cubic feet, shows that no excessive amount of materials was pumped from outside the casing, so that no correction is necessary. The only calculation necessary then is to divide the total gold, seventy four mgs., or 7.4¢, by the volume. The volume is the product of the depth of the pay horizon or mining section times the area of the shoe, or the depth of the mining section times the volume per foot of drive (the casing factor). This volume is:

$$(0.307)(10) = 3.07 \text{ cu. ft.}$$

The value per cu. ft. is:

$$\frac{7.4¢}{3.07} = 2.4¢ \text{ per cu. ft.}$$

As there are 27 cubic feet in one cubic yard

$$(2.4)(27) = 65¢ \text{ per cu. yd.}$$

Since this value is for 10 of the total depth, the value per cubic yard for the whole depth is smaller:

$$\frac{(10)(65)}{20} = 32¢ \text{ per cu. yd. for the whole depth.}$$

It should be obvious by now that as an area of 0.307 sq. ft. for the hole cut by the shoe is assumed, the value per sq. foot of bedrock is the total gold found in the hole, corrected for abnormal cores or volumes if necessary, divided by the area of the hole, 0.307 sq. feet. In the example under consideration, this value is

$$\frac{7.4}{0.307} = 24.1¢ \text{ per B.R.F. (bedrock foot) or sq. foot of bedrock.}$$

Many operators wish to know values in B.R.F. because, knowing the dimensions of the cut, they can easily compute the total value. If there are twenty seven feet of overburden over one square foot of bedrock, the value per B.R.F. is also the value per cubic yard, since there are twenty seven cubic feet to one cubic yard. If there are fifty four feet of overburden, the value per cubic yard is halved. And, if there are thirteen and a half feet of overburden, the value is

Fig. 14-7 - Drill Log, Thawed Hole

doubled. In our example there are twenty feet of material to be mined.

$$\frac{(24.1\text{¢})(27)}{20} = 32\text{¢ per cu. yard}$$

It is readily seen that this is the same value as was obtained by the other method.

The value of one cent for 10 mgs. applies to gold having a value of about \$31.30 per ounce. This value is sufficiently accurate to use on a new creek; but as soon as the true value is determined by assay, the new value should be used in computing drill holes. When computing many drill holes from the same creek, the prospector may save time by combining the factors which are constant into one constant called the creek factor, (symbolized c.k.). c.k. = (value in cents per mg. of gold) x (27). The value per cubic yard of the material from any particular drill hole is then:

$$\frac{(\text{mgs.})(\text{c.k.})}{\text{val. in cu. ft.}}$$

Frozen Holes

If the drilling is done carefully and the water measurement made without the occurrence of sloughing, the volume of a hole in frozen ground can be determined with comparative accuracy.

The precautions which can be taken to prevent sloughing, such as lowering the drill water into the hole instead of dumping it in and using ice and snow in the drill water, have been discussed. Before the evaluation of the hole in frozen ground is discussed, the effect of sloughing on the value of the hole, should it occur in spite of all the driller does to prevent it, must be considered.

Most Alaskan placers contain the valuable material in the lower part, on or in bedrock and in the gravel for a few feet above bedrock. Sloughing in the upper portion of the hole under these circumstances is likely to cause barren or low grade material to drop down to the bottom of the hole. If the hole has not reached the pay horizon when sloughing occurs, there is no effect. If such barren material sloughs into the pay horizon, likewise there will be no effect on the valuation of the hole because the volume from which the gold comes is not based on the measured volume loose as found in the volume bucket but upon the volume as found by the water measurement. The sloughing of barren material from above the pay horizon into gold bearing material below simply necessitates the panning of more material to get the gold but has no effect on the evaluation of the hole.

However, suppose that the richest part of the pay horizon is two feet above bedrock and that when the bit was drilling this level the hole was of normal size, slightly larger than the bit diameter. Then, suppose, as the bit was drilling into bedrock, the walls of the rich portion of the hole sloughed. Much more gold will be removed from the lower portion of the hole than would be if the sloughing had not occurred, and the value per cubic foot for this part of the hole will be high. At the same time the rich level from which the sloughing occurred will show, from the water measurement, a large volume with a smaller amount of gold than should have come from that volume. The net effect will be to increase the value per cubic yard of the hole. On the other hand, if low value material from high in the pay horizon sloughs into a rich portion of the pay horizon, the average value for the hole will be too low. Sloughing can be determined by an excessive amount of material brought up by the pump. As soon as such an excessive volume is noted, a new container should be provided so that a new sample can be started. This procedure limits the effect of the sloughing to one portion of the hole, as has already been explained.

The first thing that should be done with the drill log is to determine the pay horizon and to calculate from the water measurements the actual volume of the hole in this horizon. The number of pours will not come out even at the top and bottom of this section, so it is assumed that at the top of the section and at the bottom the hole is of uniform size. With this assumption it is possible to assign to the pay horizon a portion of the pours at the top and at the bottom.

From the data on the sample log this process can be illustrated. See Figs. 14-8 and 14-9. The pay horizon is from thirty two to forty one feet. At the bottom a 0.25 cu. ft. pour raised the water level from 41'-9" to 40'-8", a total of thirteen inches. As only four inches of this was above 41 feet, or in the pay horizon,

$$\frac{4}{13} = 0.08 \text{ cu. feet}$$

is in the interval from 41 feet to 40'-8". From 40'-8" to 32'-4", the depth of the last even pour in the pay horizon, there were seven pours:

$$7(0.25) = 1.75 \text{ cu. ft.}$$

Then from 32'-4" to 32', the top of the pay horizon, is four inches. 0.25 cu. ft. of water raised

FIELD LOG

FINISHED MOVING 11:15 AM Oct. 18 1948 ELEVATION 940.2 HOLE NO. 3 LINE NO. 18
 COMMENCED DRILLING 1:20 PM CO-ORDINATE _____ CREEK Phelan
 FINISHED DRILLING 2:00 PM Oct. 19, 1948 CO-ORDINATE _____ CLAIM 6 Below
 FINISHED PULLING Open WATER LEVEL _____ WITH _____ WITHOUT CASING _____

TIME OF PUMP	DEPTH OF PUMP OR CASING	CORE		Measured Volume LOOSE	Theoretical Volume	No. of Colors	Est. Value or Weight	Character Material Formation	Remarks	WATER MEASUREMENT			
		Before Pump	After Pump							DEPTH		Volume Cu. Ft.	Time
										From	To		
8:40	0-24	Open						Fr. Ice	Top of gr.				
								Mk. mass	2 1/2'				
9:00	26	"		0.110				Fr. gr. B		2"	31-1		3:04
9:25	28	"		0.120				Sand		13"	32-4	31-3	2:54
9:50	30	"		0.135				Fr. gr.		12"	33-4	32-4	2:53
10:05	32	"		0.125				Med. Sand		13"	33-4		2:51
10:20	34	"		0.145		3	1	Fr. gr.		12"	34-5		2:48
10:40	36	"		0.155		20	6	Med. clay		15"	35-5		2:46
10:55	37	"		0.168		25	10	Top BR.		14"	36-8		2:45
11:10	38	"		0.152		20	15	Fr. gr.		18"	37-10		2:43
11:20	39	"		0.165		40	25	Med. clay		16"	39-4		2:41
11:30	40	"		0.156		6	2	Some + med. BR.		13"	40-8		2:40
11:45	41	"		0.162		2	Tr	Some + med. clay		15"	41-9		2:38
12:00	43	"		0.150		1	Tr	"		13"	43-0		2:35
1:25	45	"		0.165				V. hard Fr. gran BR.		13"	44-1		2:34
1:40	47	"		0.155				"		12"	45-2		2:33
2:00	49	"		0.150				"		14"	46-2		2:31
								"		15"	47-4		2:30
								"		3"	48-10	48-7	2:28
								"			48-10		2:18
ROCKER													
TOTALS													
REMARKS <u>Drilled deep to check</u>								GOLD, ACTUAL WEIGHT. <u>61</u> MGS.				MOSS <u> </u> FT.	
<u>depth of weathering in BR.</u>								FROM _____ TO _____ MGS.				MUCK <u>24</u> FT.	
								FROM _____ TO _____ MGS.				GRAVEL <u>14.5</u> FT.	
								FROM _____ TO _____ MGS.				BEDROCK <u>10.5</u> FT.	
								FROM _____ TO _____ MGS.				TOTAL <u>49.0</u> FT.	

ABBREVIATIONS TO BE USED

Th.—Thawed Ice; Ice; V.—Very; St.—Sticky; Tr.—Trace;
 Fr.—Frozen; S.—Sand; M.—Muck; F. Gr.—Fine Gravel; B.—
 Boulder; Mk.—Muck; Sm.—Some; Med. Gr.—Medium Gravel;
 T.—Tailings; Cl.—Clay; L.—Loose; C. Gr.—Coarse Gravel;
 An.—Angular.

Time of Drilling _____ Hrs.
 Time of Pulling _____ Hrs.
 Time of Moving _____ Hrs.
 Time Lost _____ Hrs.
 Total Time _____ Hrs.

Drillmen S.K.
 Panners D.O.K.
 Checked By J.R. In Charge

Fig. 14-8 - Drill Log, Frozen Hole

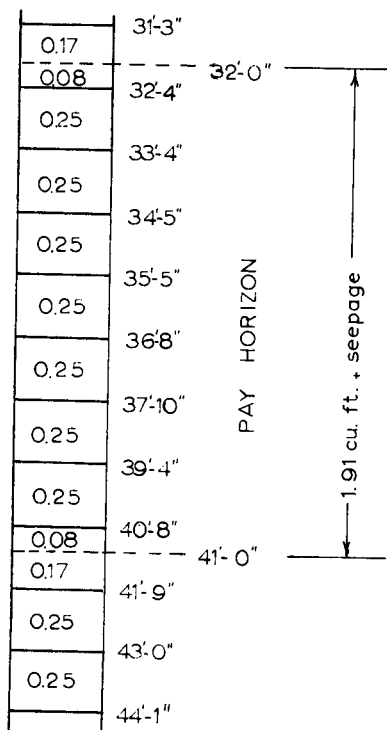


Fig. 14-9 - Relationship of Pours to Top and Bottom of Pay Horizon.

ever, the log is examined to see if there are any excessively large volumes of loose solids recorded. If there are, the log must be analyzed to determine if there was a large slough to provide the excess volume, and if so, whether it came from a rich stratum. If it did, the chances are that the calculated value per cu. yd. is high.

It is difficult to determine if there was a large slough at some point, because although a large volume might be found by water measurements at that point, there is no way of telling accurately whether the enlarged section was made during the drilling or by sloughing afterward. If a large loose volume was found lower down and the drill crew notes sloughing on the log, the engineer may assume sloughing from a certain interval. Even so, how much gold to subtract from the lower interval with the excessive loose volume and how much to add to the upper interval from which the material sloughed is a matter of opinion; and because of the uncertainties involved, many engineers will make no adjustments of this kind at all. It is difficult to say how much "judgment" would enter into this adjustment, because there is little on which to base the "judgment". The best source of confidence, again, is the carefulness of the drill crew.

On the log in the example, no excessive loose volumes were noted; consequently the average value through the pay horizon from 32 to 41 feet is computed as

$$\frac{6.1\text{¢}}{1.97} = 3.1\text{¢ per cu. foot}$$

$$(3.1)(27) = 84\text{¢ per cu. yard}$$

The value for the whole body of gravel from 26 to 41 feet, 15 feet thick, is

$$\frac{9(84)}{15} = 50\text{¢ per cu. yard}$$

and for the whole 41 feet of overburden (gravel and muck) is

the level from 32'-4" to 31'-3", or 13 inches.

$$\frac{4(0.25)}{13} = 0.08 \text{ cu. feet}$$

The proportion of the pours which were in the pay horizon is then

$$0.08 + 0.08 + 1.75 = 1.91 \text{ cu. ft.}$$

The natural seepage into this hole amounted to three inches at the bottom and two inches at the top in a ten minute interval. At the bottom a 15 inch rise represents 0.25 cu. feet and at the top a 13 inch rise represents 0.25 cu. feet. At the bottom, the seepage is

$$\frac{3(0.25)}{15} = 0.050 \text{ cu. feet}$$

and at the top it is

$$\frac{2(0.25)}{13} = 0.038 \text{ cu. feet per min.}$$

The average is 0.044 cu. feet per ten minute interval or 0.0044 cu. feet per minute. The time required to measure the volume of the pay horizon was from 2:40 to 2:53 or 13 minutes. There was then

$$(0.0044)(13) = 0.057 \text{ cu. ft.}$$

added to the volume of hole through the pay horizon by seepage. The correct volume of the hole is

$$1.91 + 0.06 = 1.97 \text{ cu. ft.}$$

Thus, the volume of dirt in place from which a known amount of gold was taken has been determined. Before proceeding, how

$$\frac{9}{41} (84) = 18.5\text{¢ per cu. yard}$$

Knowing the value per cu. yard, the value per B.R.F. is found by dividing by 27 and multiplying by the depth in feet:

$$\frac{(18.5)(41)}{27} = 28\text{¢ / B.R.F.}$$

In another method which some engineers believe gives more accurate results than merely dividing the total gold recovered by the volume of the hole through the pay horizon, all values are adjusted to a hole of constant area. A sketch of the hole through the pay horizon is made, showing each 0.25 cu. ft. volume and the depths separating these volumes. By proportion, the volume of each one foot interval through the pay horizon is found, and these volumes are tabulated with other data from the hole as follows:

Depth	Actual Volume	Measured Vol. loose	Estimated Wt. mgs.	Adjusted Wt. mgs.	Proportional Weight
34	0.481	0.145	1	1.0	0.3
36	0.463	0.155	6	6.2	2.2
37	0.205	0.168	10	10.3	8.4
38	0.206	0.152	15	15.5	12.5
39	0.167	0.165	25	25.8	25.8—Reference Interval
40	0.180	0.156	2	2.2	2.0
41	0.205	0.162	tr.	tr.	tr.
	1.907		59 mgs.	61 mgs.	51.2

Volumes, cu. ft.	Volumes, cu. ft.	Depth	Depth	Interval
			31'-3"	
	0.077	32'	32'-4"	13"
0.481	0.167		32'-4"	12"
	0.083		33'-4"	
	0.154	34'	34'-5"	13"
	0.096		34'-5"	12"
0.463	0.250		35'-5"	15"
	0.117	36'	36'-8"	14"
0.205	0.133		37'-10"	
	0.072	37'	37'-10"	18"
0.206	0.178		39'	
	0.028	38'	39'-4"	16"
0.167	0.167		40'-8"	
	0.055	39'		
0.180	0.125	40'		
0.205	0.125	41'		
	0.080			

Fig. 14-10 shows a section of this hypothetical hole. The actual volume is computed from the water measurements. The measured volume loose and the estimated weight are from the log. The adjusted weight is obtained by raising or lowering all the estimated weights in the same proportion so that their sum equals the actual weighed amount of gold. This is done by multiplying each estimated weight by the factor

$$\frac{\text{actual total weight}}{\text{sum of estimated weights}} = \frac{61}{59} = 1.03$$

(Such accurate estimating is seldom attained).

To adjust the values to a hole of constant area, a reference interval must be chosen. In this example, this reference interval is taken as 38' to 39', as it is the smallest in area. Proportional weights for the other intervals are computed by multiplying the adjusted weight for the interval by the factor

$$\frac{\text{Actual volume of reference interval}}{\text{Actual volume of interval}}$$

For example, the proportional weight for the interval 36' to 37' is

$$\frac{(0.167) (10.3 \text{ mgs.})}{(0.205)} = 8.4 \text{ mgs.}$$

Fig. 14-10 - Relationship of Volumes of Pours to Volumes of One Foot Intervals in Drill Hole in Frozen Ground.

The hole is now considered to have a constant area of 0.167 sq. ft. The volume

of the hole through the nine foot pay horizon from 32' to 41' is

$$9(0.167) = 1.50 \text{ cu. feet}$$

The sum of the proportional weights is 51 mgs. The volume of 1.50 does not take into account the volume added by seepage. To be strictly correct, the amount of seepage per minute should have been added to each 0.25 cu. ft. pour that took one minute (or the amount per two minutes for those that took two minutes). However, this amount would have little effect upon the calculation of the proportional weights; consequently seepage is added only to the total volume. This is not the whole 0.06 cu. ft. which ran in during the 13 minutes it took to make the water measurement through the pay horizon, but a part of it in the same proportion as the actual measured volume to the adjusted volume or

$$\frac{(1.50)(0.06)}{(1.90)} = 0.05 \text{ cu. ft.}$$

The adjusted volume for the pay horizon is, then, 1.50 plus 0.05 or 1.55. and the adjusted value per cu. ft. is:

$$\begin{aligned} \frac{5.1\text{¢}}{1.55} &= 3.29\text{¢ per cu. foot} & (51 \text{ mg.} = 5.1\text{¢}) \\ (3.29)(27) &= 89\text{¢ per cu. yard} \end{aligned}$$

For the whole depth of 41 feet, the value is

$$\frac{9}{41} \times (89) = 19.5\text{¢ per cu. yard}$$

This compares with 18.5¢ per cu. yard found without adjusting the hole to one of constant area. If the drive which yielded the greatest amount of gold had been of large volume instead of small, the results would have differed; the value computed by this method would have been less than that computed by the other.

General Conclusions

A few generalizations regarding drill hole calculations may be drawn. An open hole in frozen ground carefully drilled and measured usually yields a closer approximation to the true value of the ground than does a cased hole in thawed ground. A cased hole more often than not indicates a value lower than the actual value of the ground. Holes drilled on a coarse gold pay-streak usually give values lower than the true ones. Holes drilled on the margins, where the finer gold lies, usually give results more closely approximating the true values, or may be a little higher than the true ones. The top of the pay horizon is usually slightly higher than indicated by the drill because of the tendency for the gold to work down; for the same reason gold is recovered from a slightly lower depth than it actually occurs. Holes drilled in loose gravel do not yield much gold until bedrock or some other impervious layer is reached because the churning action of the bit agitates the material and keeps the fines and heavy material working down. Most of this material may be found at bedrock.

However, because there are variations in the distribution of values and formation affecting the accuracy of the evaluation of the ground that cannot be detected, the foregoing generalizations cannot be applied unreservedly. These variations, which cause large underruns and overruns, cancel each other over large areas, as was found by the U. S. Smelting Refining and Mining Company at Fairbanks, but for small areas - a particular creek or part of a creek - they may have profound effect.

EVALUATING THE GROUND FROM THE DRILL HOLES

After a value in cents per cu. yard has been determined for the ground at each drill hole, the entire drilled area is evaluated, and the amounts of muck and gravel to be stripped and of gravel to be sluiced are computed. From the drill hole data, also, the limits of pay are determined, and the position of the bedrock channel is found. From this information, the stripping limits and the position of the bedrock drain are determined.

These properties can be determined as well from shaft data as from drill hole data if the shafts are laid out in cross cuts as are the drill holes. The following discussion therefore applies whether the prospecting was done by shafts or by drill holes. After the drill holes have been calculated, the first step is to lay out on paper each drill line as a cross section. The surface, top of gravel, and bedrock are plotted and connected by lines; and each drill hole is shown with its

value per cu. yard represented by a line, a dot, or in some other way that will permit graphical comparison. In order to draw the profile of the surface, it is necessary to determine the difference in elevation between the holes with a hand level. The depths are then measured down from the surface. Next a simple map showing all holes and their values is drawn up. These basic aids to visualizing should always be prepared.

There are three principal methods of evaluating the ground: the line method, the triangle method, and the diamond method. The triangle method is further divided into the three point method and the two point method. The computations are made by blocks of ground, each block usually being that which lies between two rows of drill holes.

Line Method

Although the line method may be used for ground which has been prospected exhaustively, its chief use is for ground which has undergone preliminary drilling, with lines spaced at relatively long intervals and when only the total value and yardage of each block is desired. If the drill lines are not straight or not at right angles to the paystreak, a straight line is drawn on the map at right angles across the paystreak and each hole projected to it.

It is assumed that the effect of each hole extends half way to the adjacent holes. The value per cu. yard at the hole times the distance along the drill line affected by that hole (one-half the sum of the distances to the two adjacent holes) times the depth gives the weighted value to be used for that hole. If the value were given in cents per cu. foot, this product of value times width affected times depth affected would give the number of cents in a strip one foot thick from the surface to bedrock and as long as that section of the line influenced by the hole. The sum of these products (for all the holes in the line) would give the cents in a one foot slice all the way across the paystreak. In practice, however, it is more convenient to leave the values in cents per cubic yard, and to divide by 27 later to get dollars per cu. foot. It is also more convenient to use as the distance affected by each hole the sum of the spacings on each side. This is twice the distance influenced by each hole, but the sum of the (values) \times (spacing) \times (depths) can be divided by two when the calculation is finished.

The sum of the products of (depth) \times (spacing) divided by two gives the area of the cross section at the drill line. If only the depths of muck are used, the area of the cross section of the muck is obtained; if the depth of the gravel is used, the cross-sectional area of the gravel is obtained; and if the thickness of the pay horizon or pay section is used, the area of the cross-section of pay dirt is found.

These computations are made for all the lines, and the total yardage for any one block is calculated by multiplying the distance between lines by the average of the cross-sectional areas of the lines at each end. This result gives a volume in cubic feet which is divided by 27 to give the volume in cubic yards. Again, in practice, the two cross-sectional areas are added together, their sum multiplied by the length of the block, and this value divided by two (to average the areas of the ends) and by 27 (to convert cu. feet to cu. yards).

To save time and to preserve a systematic record of the calculations, all data are tabulated, and the computations made on the same sheet, as in Table 14-1. Fig. 14-11 shows the block of ground. The drill hole data used in this example have no connection with the sample drill logs previously shown.

Table 14-1

Line	Hole	Spacing	Thickness		Pay Horiz.	Pay Horiz. Val. per cu. yd.	Muck xSpace	Gravel xSpace	Pay Horiz. xSpace	Pay Horizon xVal.
			Muck	Gravel						
18	4		0	27	10	.54	0	1080	400	216
	5	40	10	31	10	.87	780	2418	780	679
	6	38	12	27	10	1.43	936	2106	780	1115
	7	40	11	24	10	.72	880	1920	800	576
	8	40	9	25	10	.48	360	1000	400	192
TOTAL							2956	8524	3160	2778
ONE HALF							1478	4262	1580	1389
19	2		8	25	10	.49	224	700	280	137
	2A	28	9	29	10	.78	612	1972	680	530
	3	40	12	21	10	.97	936	1638	780	757
	4	38	14	22	10	.83	1092	1716	780	647
	5	40	11	26	10	.51	440	1040	400	204
TOTAL							3304	7066	2920	2275
ONE HALF							1652	3533	1460	1138

The volumes are:

$$\frac{(1478+1652)(500)}{(2)(27)} = 28,981 \text{ cu. yards muck.}$$

$$\frac{(4262+3533)(500)}{(2)(27)} = 72,176 \text{ cu. yards gravel total.}$$

$$\frac{(1580+1460)(500)}{(2)(27)} = 28,148 \text{ cu. yards gravel in pay horizon.}$$

$$28,981 + 72,176 = 101,157 \text{ cu. yards muck and gravel.}$$

$$72,176 - 28,148 = 44,028 \text{ cu. yards gravel to be stripped.}$$

$$\frac{(1389+1138)(500)}{(2)(27)} = \$23,396 \text{ total value of block.}$$

The value per cu. yard for the whole body, both muck and gravel is:

$$\frac{\$23,396}{101,157} = \$0.23 \text{ per cu. yard,}$$

and for the gravel alone is:

$$\frac{\$23,396}{72,176} = \$0.32 \text{ per cu. yard,}$$

and for the pay horizon alone it is:

$$\frac{\$23,396}{28,148} = \$0.83 \text{ per cu. yard.}$$

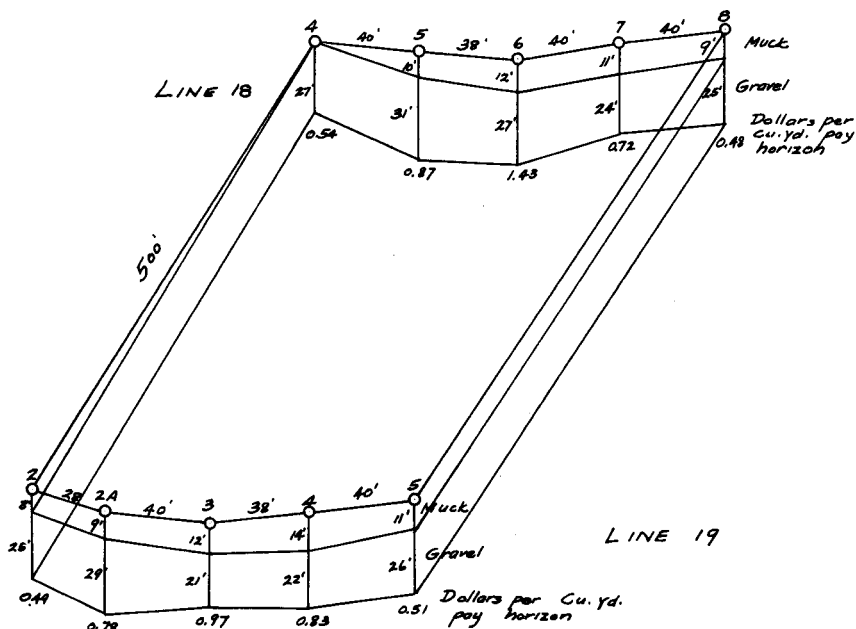


Fig. 14-11 - Block of Ground Laid Out for Line Method

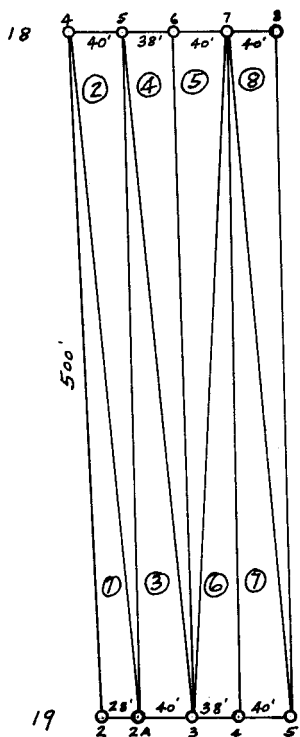
Three Point Triangle Method

The same block of ground is now calculated by the three point triangle method. Triangles are laid out connecting two holes of one line and one hole of the next line, the long dimension being parallel to the paystreak. Thus, each triangle occupies a longitudinal area in the paystreak, which makes it less likely to cut across from rich ground in the center to marginal ground on the edges. In this way the rich holes of two lines form triangles and the poor holes of two lines form other triangles. Groups of closely spaced holes that would make excessively long thin triangles are averaged and considered as one hole. Rich holes should be so joined to limit their influence to the smallest area possible; except to localize the effect of these rich holes, the triangles should be as nearly equal in area as possible. Fig. 14-12 shows the block laid out for this method.

The average depth of the three holes is computed and also the average value per cu. yard. The volume in cu. feet of the ground under the triangle is the area of the triangle times the average depth; this volume divided by 27 is the volume in cu. yards. The total value for the triangle is the average value for the three holes times the volume. All data for all triangles in a block are tabulated and the triangle volumes and values are added to get the totals for the whole block. The lengths of the sides of each triangle are found by scaling the map. Ordinarily the triangles are so long and narrow that it is sufficiently accurate to assume that the short side is perpendicular to one of the long sides. If the triangle is more nearly equilateral, a perpendicular (height) must be drawn to one of the legs (base).

$$\text{Area} = \frac{(\text{height})(\text{base})}{2}$$

Tabulations in the following table (Table 14-2) apply to the same block of ground as in the previous example.



AREAS

$$\textcircled{1} \quad \frac{28(500)}{2} = 7000 \text{ Sq. ft.}$$

$$\textcircled{2} \quad \frac{40(500)}{2} = 10000$$

$$\textcircled{3} \quad \frac{40(500)}{2} = 10000$$

$$\textcircled{4} \quad \frac{38(500)}{2} = 9500$$

$$\textcircled{5} \quad \frac{40(500)}{2} = 10000$$

$$\textcircled{6} \quad \frac{38(500)}{2} = 9500$$

$$\textcircled{7} \quad \frac{40(500)}{2} = 10000$$

$$\textcircled{8} \quad \frac{40(500)}{2} = 10000$$

Fig. 14-12 - Block of Ground Laid Out for Three Point Triangle Method

Triangle Three Point Calculations

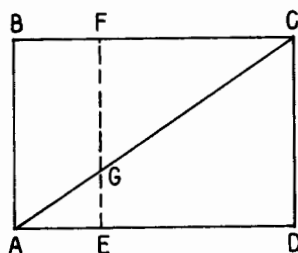
Triangle Three Point Calculations														
Triangle	Line	Hole	Depth			Area	\$Val. per cu. yard	Pay Horiz. (\$ per sq. ft.)	Gross Value	Volume cu. yards				
			Muck	Gravel	Pay Horizon					Muck	Gravel	Horizon	Total	
								(Depth)(Depth) (cu. yd)	(Area) x (\$ per sq.) (ft.)					
1	18	4	0	27	10	7000	0.54	27		1540	1480	7000	2590	8480
	19	2	8	25	10		0.49							
	19	2A	9	29	10		0.49							
			17	81	30		0.78							
			5.7	27	10		1.81							
						0.60	0.22							
2	18	4	0	27	10	10,000	0.54							
	18	5	10	31	10		0.87							
	19	2A	9	29	10		0.78							
			19	87	30		2.19							
			6.3	29	10		0.73							
						0.27			2700	2330	10700	3700	13030	
3	18	5	10	31	10	10,000	0.87							
	19	2A	9	29	10		0.78							
	19	3	12	21	10		0.98							
			31	81	30		2.62							
			10.3	27	10		0.87							
						0.32			3200	3820	10000	3700	13820	
4	18	5	10	31	10	9,500	0.87							
	18	6	12	27	10		1.43							
	19	3	12	21	10		0.97							
			34	79	30		3.27							
			11.3	26.3	10		1.09							
						0.40			3800	3970	9260	3520	13230	
5	18	6	12	27	10	10,000	1.43							
	18	7	11	24	10		0.72							
	19	3	12	21	10		0.97							
			35	72	30		3.12							
			11.7	24	10		1.04							
						0.39			3900	4330	8900	3700	13230	
6	18	7	11	24	10	9,500	0.72							
	19	3	12	21	10		0.97							
	19	4	14	22	10		0.83							
			37	67	30		2.52							
			12.3	22.3	10		0.84							
						0.31			2950	4330	7850	3520	12180	
7	18	7	11	24	10	10,000	0.72							
	19	4	14	22	10		0.83							
	19	5	11	26	10		0.51							
			36	72	30		2.06							
			12	24	10		0.69							
						0.26			2600	4450	8900	3700	13350	
8	18	7	11	24	10	10,000	0.72							
	18	8	9	25	10		0.48							
	19	5	11	26	10		0.51							
			31	75	30		1.71							
			10.3	25	10		0.57							
						0.21			2100	3820	9260	3700	13080	
TOTALS						76,000			22,790	28,530	71,870	28,130	100,400	

Table 14-2 - Triangle Three Point Calculations.

Summary

28, 530	cu. yards muck
71, 870	cu. yards gravel
28, 130	cu. yards to be sluiced (Pay Horizon)
43, 740	cu. yards gravel to strip
100,400	cu. yards total gravel and muck
\$22,790	gross value
\$22,790	
28,130	\$0.81 per cu. yard (Pay Horizon)
\$22,790	
100,400	\$0.23 per cu. yard (Gravel and muck)

TWO POINT TRIANGLE METHOD - A variation of the three point triangle method just described is the two point method. This is identical to the three point method except that the value per cu. yard for the triangle is taken as the average value of the two holes forming its base rather than of all three holes. The reason for using this system is seen from the following explanation. The value of a quadrilateral is determined from the two triangles that compose it. Thus, in Fig. 14-13, the value of the quadrilateral ABCD is the sum of the values of the triangles, but in computing these triangles, holes A and C are used twice and holes B and D only once. If the diagonal were changed to extend from B to D, B and D would be used twice and A and C only once. Evidently the choice of the corners marking the ends of the diagonals influences the evaluation of the quadrilateral. If the value per cu. yd. of the triangle ABC is



taken as the average of the values of the holes A and B, and the value of triangle ACD is taken as the average of the values of C and D, the choice of diagonals does not affect the value of the whole. Further, if it is desired to exclude a portion of the quadrilateral, say, everything to the right of the dotted line, the effect of holes C and D is small compared with that of A and B. (Although the average value of the small triangle AEG is determined by holes C and D, the proportion of the area AEFB influenced by these holes is small.) Wherever the dotted line is chosen, the effects of the different holes is automatically adjusted by the proportion of the area of the triangles included in the desired area.

Diamond Method

Fig. 14-13 - Two Point Triangle

The third method of computing values from drill holes is called the diamond method, from the shape of the areas used. The diamond has its center at a drill hole and its apexes at points midway between holes on the two adjacent lines. The one hole at the center of the diamond, therefore, determines the value of the diamond. Computations using the diamond method are simpler than those using the triangle method but not so simple as those using the line method. Practice has determined that the diamond method may be the best one to use when the holes are regularly spaced but that in general it has no advantage over the triangle method other than simplicity. For ground prospected with irregularly spaced holes it is inferior to the triangle method and about equal to the line method. One advantage of the diamond method over the line method is that the degree of influence of a hole can be varied to some extent by the choice of apex points.

The following plan and tabulation (Fig. 14-14) show the calculation of a block of ground by the diamond area system. Each "diamond area" is actually only that portion of the diamond which falls in the block being calculated. For those diamonds not touching the limits, the areas are half the full diamond area; for those on the limits (diamonds 1, 5, 6, 10 in the diagram) the areas are determined by scaling the map or calculating to get the dimensions of the parts actually in the block and then computing the areas of the small figures. The calculation of some of these areas in the following example illustrates the method.

On these long narrow diamonds, no appreciable error is introduced by assuming the half diamond to be a right triangle and the length of a side to be 500 feet; if the diamonds were shorter, it would be necessary to drop a perpendicular to the base and to scale its length. The area of each half diamond then is calculated as the area of a right triangle; for half diamond 2 it is:

$$\frac{(500)(40)}{2} = 10,000 \text{ sq. feet.}$$

The areas of the other interior diamonds are found similarly.

That part of the area of diamond 10 which lies inside the block is found to be a triangle of base 206 feet (scaled from map or computed) and altitude 14 feet, equaling 1440 sq. feet. The area of that part of diamond 5 lying inside the block is found by subtracting the area of the small triangle outside the block from the area of the half diamond. The area of the half diamond is

$$\frac{(40)(500)}{2} = 10,000 \text{ sq. feet.}$$

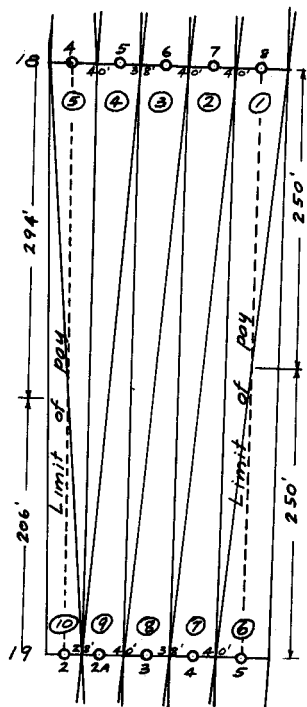
and that of the small triangle outside the block is

$$\frac{(294)(20)}{2} = 2,940 \text{ sq. feet.}$$

The desired area is

$$10,000 - 2,940 = 7,060 \text{ sq. feet.}$$

The areas of diamonds 1 and 6 are calculated similarly. Value per B.R.F. is found by multiplying value per cu. yard of pay horizon by 10/27.



AREAS

$$\begin{aligned}
 ① & \frac{(40)(500) - (20)(250)}{2} = 7500 \\
 ② & \frac{(40)(500)}{2} = 10000 \\
 ③ & \frac{(39)(500)}{2} = 9750 \\
 ④ & \frac{(39)(500)}{2} = 9750 \\
 ⑤ & \frac{(40)(500) - (20)(294)}{2} = 7060 \\
 ⑥ & \frac{(20)(250)}{2} = 2500 \\
 ⑦ & \frac{(39)(500)}{2} = 9750 \\
 ⑧ & \frac{(39)(500)}{2} = 9750 \\
 ⑨ & \frac{(34)(500)}{2} = 8500 \\
 ⑩ & \frac{(14)(206)}{2} = 1440
 \end{aligned}$$

Fig. 14-14 - Block of Ground Laid Out for Diamond Method Calculation.

Table 14-3 Diamond Method Calculations

Diamond	Line	Hole	Depth in feet				Area	Values			Volume cu. yds.			Total Muck & Grav.
			Muck	Grav.	Pay Hor.	Total		\$ per cu. yd. Pay Hor.	\$ per sq. ft.	\$ Gross	Muck	Gravel	Horiz.	
6	19	5	11	26	10	37	2500	0.51	0.19	475	1020	2400	925	3420
1	18	8	9	25	10	34	7500	0.48	0.18	1350	2500	6950	2780	9450
7	19	4	14	22	10	36	9750	0.83	0.31	3020	5050	7940	3610	12990
2	18	7	11	24	10	35	10000	0.72	0.27	2700	4080	8900	3700	12980
8	19	3	12	21	10	33	9750	0.97	0.36	3510	4330	7590	3610	11920
3	18	6	12	27	10	39	9750	1.43	0.53	5170	4330	9750	3610	14080
9	19	2A	9	29	10	38	8500	0.78	0.29	2465	2830	9130	3150	11960
4	18	5	10	31	10	41	9750	0.87	0.32	3120	3610	11150	3610	14760
10	19	2	8	25	10	33	1440	0.49	0.18	259	426	1330	530	1756
5	18	4	0	27	10	27	7060	0.54	0.20	141	0	7060	2620	7060
TOTALS							76000			22210	28176	72200	28145	100376

The average values per cu. yard are:

$$\frac{\$23,230}{27,777} = \$0.84 \text{ per cu. yard of pay horizon}$$

$$\frac{\$23,230}{99,940} = \$0.23 \text{ per cu. yard of gravel and muck.}$$

Comparison of Methods

The results obtained by the line method, the triangle method, and the diamond method are tabulated in Table 14-4.

Table 14-4 Comparison of Methods of Calculating Drill Results

Method	Area	Cu. yds Muck	Cu. yds Gravel	Cu yds. Pay Horizon	Cu yds. Total	Total Value	Value per cu. yd. Pay Horizon	Value Cu. yd. Total
Line	76,000	28,981	72,176	28,148	101,057	\$23,396	\$0.83	\$0.23
Triangle	76,000	28,530	71,870	28,130	100,400	\$22,790	\$0.81	\$0.23
Diamond	76,000	28,176	72,200	28,145	100,376	\$22,210	\$0.79	\$0.22

These figures speak for themselves. The following observations have been found by experience. The line method involves the shortest computation and is used for calculating the results of reconnaissance drilling where the lines are far apart and the results necessarily will be approximate. The triangle method involves the longest computation but is the most accurate because the value of each triangle is obtained from the average of three holes and because the effect of these holes can be localized into one or two triangles. The calculation by the diamond method is quicker than by the triangle method, but as the value of each diamond is based upon a single drill hole, it is not so accurate. For ground drilled with holes of fairly uniform spacing and values, the diamond method is as accurate as the triangle method.

When the value of a block of ground is being computed by the triangle or the diamond method, the effect of rich holes should be isolated so much as possible. For this purpose the diamond method is well suited because the corners of the diamond representing a rich hole can be chosen so as to reduce the size of the diamond and hence the rich area. However, this adjustment is an arbitrary one which can be justified only by considering it an added safety factor. The best procedure to follow if it is suspected that a particularly rich hole is not representative of the true value is to drill another hole near it.

CONCLUSION

For several reasons more space has been devoted to the discussion of drilling than to the other methods of prospecting. As stated before, all large scale placer prospecting programs are carried out by drilling for the simple reason that, although drill holes yield smaller samples than shafts, many more samples are obtained by the drill for the same expenditure. Since the depth information provided by drill holes is as accurate as that provided by shafts, each additional hole drilled for the same cost as that of sinking one shaft represents a considerable gain. A few points bear repeating: Values obtained by drill holes should always be checked by some other method before large expenditures are made on mining equipment, unless such values are uniformly rich enough to insure a profitable operation assuming a liberal margin of safety. In shallow ground the best way to check the drilling is to put in a small open cut. In deeper ground the best way to check the drilling is to put in a few shafts to provide a comparison; and in old drifted ground the results of the drifting, if known, may provide the desired information. Whenever old drifts are included within a block, their production should be subtracted from the computed value of that block. When holes are drilled into the drifts, the area of the drifts should be taken into account when determining the influence of those holes. It should always be remembered that the purpose of exploration by drill holes, or by any method, is to determine at the least cost whether the ground being explored can be worked at a profit. When the ground being explored is rich, this fact can be determined readily; likewise, if it is poor, no question of judgment arises. But, when the ground is marginal, all possible checks and precautions must be made, and even then an element of risk always remains. It is under such circumstances that mining becomes a gamble, the outcome of which depends upon how the equipment operates, how easily the ground can be dug, how efficient the workers are, even how well the weather cooperates. Fi-

nally, it should be remembered that the more ground available to be drilled, the more accurate the drilling over the whole area will be. The gold recovered from a small area - for instance, a part of one creek - may greatly overrun or underrun the prospect values when it is mined.

References

- Nordale, Arnold, 1935, Description of Fairbanks Prospect Drilling Methods: U.S.S.R. and M. Co. (Unpublished)
- Peele, Robert, 1941, Mining Engineers' Handbook, 3rd Ed. : John Wiley and Sons, Inc., New York
- Picotte, Gordon, 1941, Exploration of placer deposits in Alaska: Unpublished B.S. thesis, Univ. of Alaska
- Stardrill-Keystone Co., 1956, Various literature on Water Well Drilling: Beaver Falls, Pennsylvania

Chapter 15

GEOPHYSICAL, GEOCHEMICAL AND MINERALOGICAL PROSPECTING

In the general discussion of prospecting (Chapter 10) thirteen methods were listed. The last three, geophysical, geochemical, and mineralogical prospecting, require a more detailed discussion and are the subject of this chapter.

GEOPHYSICAL METHODS

For several reasons, none of the methods which are to be described have been applied to any great extent in Alaska. First, geophysical methods have only a limited application to ore mineral prospecting. (Where oil prospecting is in progress in Alaska, certain geophysical methods are applied extensively). Another reason for their not being used much in Alaska is that the cost of most of them makes it impossible for any but a well financed group to utilize them. Further, the interpretation of geophysical data usually must be done by one who has made it his life work. For these reasons, most of the following descriptions are brief, this chapter containing only enough information so that the prospector can determine whether a particular method might be applied to a particular problem with reasonable expectation of useful results. An exception to this is the discussion of the magnetic method, which is described in more detail.

Geophysical methods, as the name implies, are those in which some physical property is measured. These methods cover a wide range. Geophysical prospecting has been brought to a high level of usefulness and has paid great dividends in the oil industry; in fact "seismic" methods - the study of the speed with which materials transmit sound waves - is an essential step in oil prospecting. Some of the geophysical methods used in oil prospecting have a limited application to ore mineral prospecting; other methods are more widely used. None, however, is as universally applied to ore mineral prospecting as are seismology, gravimetry, and magnetometry to oil prospecting. All geophysical results must be interpreted in conjunction with geological evidence.

Before attempting any geophysical work or engaging others to do geophysical work for him, the prospector should understand just what properties of his deposit he is measuring and decide whether this physical property differs enough from place to place to be detected. This may not always be determined in advance, but some methods may be discarded at once as having no chance of success while others may be worth trying. The following is a brief description of the principal methods, their uses and possible applications in Alaska. In geophysical prospecting, the prospector searches for anomalies, or deviations from the common rule. What the anomalies mean must be decided from experience.

Seismic

In seismic prospecting a small charge of dynamite is set off in a hole from which sound waves travel in all directions. These sound waves are picked up at selected points in the area by "geophones" which vibrate and create tiny electrical currents that are amplified and sent to galvanometers which deflect. Small mirrors mounted on the galvanometers reflect light beams onto moving photographic papers, thus producing a record of the earth vibrations. The time elapsed between the firing of the shot and the arrival of the sound wave at the geophone, together with the known distance between the shot and the geophone, enable the depth to a reflecting layer to be computed. The depths to certain beds of sedimentary rocks are thus determined. To justify drilling for oil, there must be first, sedimentary rocks of the right age present, rocks porous enough to hold the oil, and third, a structure which can trap and collect the oil. The seismic method, by determining the depths to certain layers or beds, is very important in ascertaining underground structure, and hence indispensable to the oil industry.

What are the applications of seismology to prospecting for ore minerals? About the only applications which suggest themselves are the determination of depth of overburden on placer ground or on a lode deposit which is to be open cut or in finding intrusives which do not outcrop. Compact seismic prospecting equipment has been developed with which the geophysical prospector can determine depths to bedrock to within a few feet.

On deep creeks, if the location of the channel is known before drilling or sinking starts,

much preliminary work can be saved. On such creeks several seismic depth determinations across the creek might give the location of the channel. The first shot would be set off at a point on a line crossing the creek, and several geophones placed in a straight line upstream or downstream would pick up the sound waves. The whole line of geophones and the shot would then be moved toward one limit or the other, and another shot made. In this way depth determinations of a cross section of the creek could be obtained, and drilling or sinking could be started at the deepest part. Here, as in the other geophysical methods to be described, the prospector must consider this: the cost of a seismic survey might be as much or more than the cost of a small drill and a summer's drilling. Therefore, unless very favorable conditions for seismic prospecting exist, in placer prospecting such a program should be passed up in favor of drilling.

It should be remembered that seismic methods determine structure. There are problems in prospecting for certain types of lodes which might be solved by a seismic survey. An actual example from Alaska illustrates such a problem. Some of the tin lodes of Seward Peninsula occur in granite pegmatite dikes and granite intrusions into limestone. The location of new buried intrusions by diamond drilling or drifting is costly, and if the contact between the granite and the limestone could be located by seismic methods, a seismic survey might prove very worthwhile.

GRAVIMETRIC

Gravimetric surveying or the measurement of the variations of gravitational attraction over an area is another common and powerful method in oil prospecting. The instruments are very delicate, and the positions of the stations must be located accurately since gravitational attraction varies with elevation and latitude. In order to eliminate these effects so that the anomaly can be recognized, precise surveying is required. This is the most expensive item in the gravimetric survey.

Rocks of different densities exert different amounts of gravitational attraction upon the gravimeter. These are tiny differences, and very sensitive instruments are necessary to detect them. Like the seismic survey, the gravitational survey is used chiefly to outline large structures in oil surveying. The only application to mineral prospecting is where fairly large structures are involved, or where the gravity differences are marked. Thus gravity measurements were used to locate several chromite ore bodies in Cuba. It will be recalled (Chapter 7) that chromite ore occurs in segregations of basic rock from the magma; basic rock is denser than acidic rock; therefore an increased gravitational pull is expected over such a body. They have been used to locate sinkholes in limestone that have been filled with overburden containing accumulated barite. It is also possible that the Alaskan tin bearing granitic mentioned as a possible field for the use of the seismograph also could be located by means of the gravimeter.

Gravity measurements are made in oil prospecting on the corners of squares a half to two miles on a side. In mineral prospecting, however, this spacing must be greatly reduced, say to 50 or 100 feet. Results are usually plotted as "gravity contour maps", or maps showing lines of equal gravitational attraction. They may, however, be plotted as profiles across the structure; the anomaly, if any, occurs over the feature sought. Salt plugs, with which oil is often associated, have a low attractive force and are found readily with the gravimeter.

To show the true significance of gravitational anomalies, the effects of regional changes must

be subtracted from those of purely local changes. Fig. 15-1 illustrates this. In the first diagram the line ACB represents the gravity along a line. C evidently represents a negative anomaly. It is assumed that the slanted line AB represents the part of the gravitational pull due to a decrease in gravity from left to right across the region. Subtracting the effect of the straight line AB from that of ACB, leaves A'C'B', which shows that part of the pull attributable to the anomaly.

The effect of "drift" must also be eliminated (actually before any other adjustments are made). The parts making up the instrument are not perfectly elastic, and during the course of a survey,

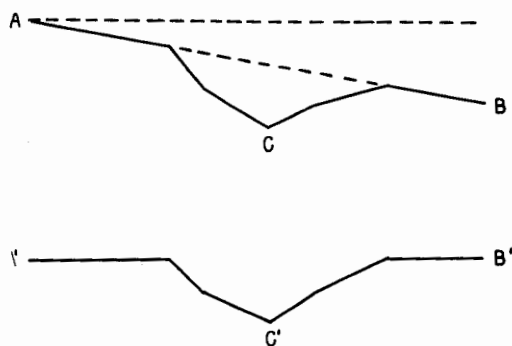


Fig. 15-1 - Subtracting Effect of Regional Changes from Gravimetric Results

tend to stretch slightly. By frequently checking back to a station previously occupied, the change due to drift can be determined. The values of gravity for the same station are plotted against the time of the reading, and a straight slanted line drawn through the resulting points. A horizontal line is drawn through one of the points, usually the first, to which the others are corrected. The difference between the horizontal line and the slanting line at any particular time must be added to or subtracted from any reading made at that time. This adjustment is similar to that made for diurnal variation in magnetometric surveys, which will be considered next. Gravimetric readings are taken in milligals, or the thousandth parts of a gal (after Galileo). A gal is the strength of a gravitational field which will attract a mass of one gram with a force of one dyne. Since the earth's gravitational field has a strength of about 980 gals, the milligal is about one millionth of the strength of the earth's gravitational field. Such minute variations, of course, are obscured by the effect of temperature changes upon the instrument, consequently the older instruments were very closely temperature controlled by electric heating. Later models are temperature compensated, doing away with the necessity of carrying batteries.

Magnetic

Magnetometric, or simply, magnetic methods, have the most widespread application to mineral prospecting. In a recent paper in "Geophysics", it was stated that 95% of the geophysical work on the Canadian shield in 1947 consisted of magnetometer surveys for gold and base metals in drift covered areas; the application to Alaska is obvious.

There are now two different types of magnetic survey methods in use: the ground survey and the airborne survey. Ground survey methods are chosen with the required degree of sensitivity and accuracy in mind. Surveys to locate bodies of magnetite, which is exceedingly magnetic, or of ultrabasic rocks, which owe their magnetism to included magnetite, are made with insensitive instruments. Surveys to trace structures, or to locate a thin layer of magnetic black sands associated with a placer paystreak, are made with a sensitive magnetometer.

The earth is everywhere surrounded by a magnetic field. In the interior of Alaska the lines of force which make up this field are entering the earth at about 75° from the horizontal. If the field is resolved into its vertical and horizontal components, it is seen that the vertical component is much stronger than the horizontal. In almost all magnetic surveys, the vertical component is the one measured. The unit of magnetic field strength is the gauss, or one line of force per sq. cm., and the practical unit is the 100,000th part of a gauss, or the gamma.

Magnetic storms are periods during which the earth's field varies widely and rapidly. The earth's field on a magnetically "quiet" day undergoes a small smooth variation known as the diurnal variation. It is on such quiet days that magnetometric surveys must be made during the time least likely to be disturbed, the period of two or three hours before and after noon. The earth's field is influenced by particles emanating from the sun, and since the same spot on the sun points at the earth about every twenty seven days, there is a tendency for quiet or disturbed conditions to repeat every twenty seven days. The geophysical prospector takes advantage of this fact in planning his work, and before leaving for the survey he requests the personnel of the nearest U.S. Coast and Geodetic Survey Magnetic Observatory to make a forecast of conditions for the period of the survey. By consulting the records of the strength of the earth's field during the past twenty seven days, they pick the days which they consider will be the quietest during the next twenty seven days.

For surveys of magnetite bodies, the dip needle is sufficiently sensitive. The dip needle can detect variations of about 300 gammas; that is, a change of 300 gammas will cause it to change its position enough so that it can be read and noted.

In the dip needle survey, a grid is laid out and readings are made at the intersections. The distance between stations, as in other geophysical surveys, depends upon the size of the body sought. Most often, a non-magnetic tripod to hold the dip needle is used, but where anomalies are large, the instrument can be held in the hands. In taking a dip needle observation, a compass is first used to determine the magnetic meridian or the direction of the field (magnetic north). If the dip needle is oriented so that the needle is free to rotate in the magnetic meridian, changes in needle position measure variations in the total field; if oriented at right angles to the magnetic meridian, changes in needle position measure variations in the vertical component.

Dip needles are not so sensitive that temperature or diurnal variation corrections must be made, although such surveys should not be attempted during magnetic storms.

The magnetometer is used for surveying structures or placers in which small anomalies are involved. This instrument consists of a magnet system inside an insulated box and a telescope for reading the scale. The magnet system has two flat magnets, one on either side of an aluminum block to which are fastened quartz knife edges which rest on cylindrical quartz bearings. On top of the block is a mirror which reflects light coming through a window and sends it through the telescope to the eyepiece. A piece of glass in the telescope system contains a fine etched scale, and the window contains an etched line. The mirror moving with the magnet system causes the image of the fine line to move back and forth across the scale, and since the

position of the magnet system and its attached mirror is determined by the strength of the field, the strength of the field is measured by the position of the image of the line on the scale. The magnetometer is mounted on a non-magnetic tripod, the head of which is oriented in the magnetic meridian (or at right angles to it) with a compass.

In a magnetometer for measuring the vertical component of the field, the magnets are horizontal and at right angles to the magnetic meridian. In a magnetometer for measuring the horizontal component, they are vertical and are parallel to the magnetic meridian.

The chief use for the magnetometer in Alaska for some time to come probably will be to locate placer paystreaks, although its use in oil prospecting may become increasingly important. The concentrates associated with placer gold in most paystreaks contain magnetite - magnetic black sands. If the bedrock consists of rock containing little magnetite and if the placer is not buried too deeply, the magnetometer may detect the placer magnetite.

In practice, the magnetometer is set up at some place away from metal and calibrated in gammas per scale division. This is done by passing a known current through a standard (Helmholtz) coil surrounding the instrument, or by placing standard magnets at known distances from the instrument. When using the coil, different currents are sent through in one direction and then the other, and the deflection of the magnet system for each current is noted. From the dimensions of the coil and the number of turns, the magnetic field per unit of current (the milliampere in this case) can be computed. Knowing this, the scale deflection per gamma change in magnetic field can be computed. Commercially built coils carry the manufacturer's calibration.

Similarly, the field produced by a standard magnet at a known distance can be computed, and by varying the distance and by pointing first the north end and then the south end of the magnet toward the magnetometer, the deflection in scale divisions per gamma change is computed. Usually in practice the coil is used to calibrate the magnetometer and to standardize the magnets before the field party leaves for a survey. While in the field only the magnets are used because the coil with its accessory batteries and milliammeter is bulky and heavy, and the magnets will fit into a shirt pocket. Calibration with magnets in the field is not necessary unless the instrument is jarred; it is, however, good practice to check the calibration occasionally.

When a survey is contemplated, the first move is to go over the geological evidence to answer the question, "Is a magnetic survey applicable?" If a lode is sought, is there likely to be a great enough difference in magnetic attraction between the lode and the country rock, and is it shallow enough to be detected? (Magnetic attraction decreases rapidly with distance). If a placer is sought, the bedrock must be non-magnetic; it should be shallow, and there should be magnetite in the concentrates. There is an exception to this last rule; if there is no magnetite in the concentrates, and the bedrock is fairly magnetic, the deepest part of the creek may show a negative anomaly (less attraction). If the placer occurs in the "channel" or deepest part, this negative anomaly may be used to locate it.

After the party reaches the area to be surveyed, a base station is picked near the cabin or tent, and the instrument set up and observed at one-minute intervals. Older magnetometers required corrections for temperature variations. If such an instrument is used, the variation in scale divisions per degree centigrade is determined at this time by heating the magnetometer in the cabin and observing the scale reading as the temperature drops. If the magnetic field is stable, the variation of scale reading with temperature can be determined. Modern magnetometers do not require temperature corrections.

Next, assuming stable magnetic conditions still exist, the magnets are brought out to determine the sensitivity of the instrument (gammas per scale division). During the entire survey and its attendant traveling, the magnets are packed in cotton when not in use, and great care is taken not to jar them, for unless their strength is kept constant, they cannot be used to calibrate the magnetometer should the need arise. The strength of the field in gammas due to each magnet at standard distances from the instrument is known; the distances are marked on a brass rod which extends below the instrument. The magnets are clamped to the rod at the different distances, oriented first with the north end toward and then away from the magnetometer. The difference between the scale readings for reversed positions is twice that due to the field of the magnet at that distance, and the sensitivity in gammas per scale division is computed.

Lines across the trend of the deposit (either a placer or a lode) are laid out, and a stick with little flag is placed at each station (the point at which a measurement is to be made). The spacing of stations depends upon the size of the body sought, just as does the spacing of drill holes. Lines on a creek might be 500 feet apart, with stations twenty five or fifty feet apart; searching for a lode, the spacing might be closer. The laying out of the stations is generally with tape and Brunton compass. Such surveying work is saved for magnetically disturbed when magnetometer work is impossible.

After the magnetic field at the base station has been determined, the stations nearby are located, and readings are taken. If two magnetometers are available, the sensitivity of the instrument is determined, and one is left behind at the base station with an operator who takes readings at approximately half hour intervals so that a record of diurnal variation is kept. If an auto-recorder is available, no operator is needed. For operations at remote localities, however, it is necessary to use only one magnetometer, and to keep a record of diurnal variation by check-

ing back to the base station at intervals of an hour or less. As the distance from the base station to the stations being occupied becomes greater, too much time is consumed in walking. Sub-bases are then established and compared several times with the main base station. If this is done on a quiet day, the relative strength of the field at each sub-base is established, and it is not necessary to check in at the main base every hour. Checks to the nearest sub-base should be made each hour and to the main base before and after the day's work.

Before taking a reading, the magnetometer operator removes all magnetic material from his person, especially from near his head (as eye glasses). If he is working alone, he places his magnetic articles several feet from the station; if he has a recorder, the recorder carries all the necessary equipment, such as watch, knife, axe, etc. The recorder keeps several feet away from the instrument during observations. When two men work together, the observer carries the tripod and sets it up at the station; the recorder carries the instrument and hands it to him when he is ready. The recorder also keeps a sketch map of the area and makes temperature corrections if necessary. Spaces in the notebook are provided for readings "East" and "West"; in case of a vertical magnetometer, with "north end east" and "north end west". Spaces are also provided for the average of these readings, for time, temperature, temperature correction if applicable, diurnal variation correction, and corrected value.

Since in magnetometric prospecting, it is the difference in the strength of the magnetic field from station to station which is sought, the absolute value in gammas is not used. The absolute strength of the vertical component of the field in Interior Alaska is about 260,000 gammas, but in practice a value is assigned to the base station, large enough so that it will not be necessary to use negative numbers, say 2500 gammas. The strength of the field at all other stations is then relative to that at the base station, so many gammas above or below the 2500 gammas of the base.

Diurnal variation is corrected in the following manner. Suppose magnetic observations could be made from ten A.M. to one P.M. The scale reading is made at the base station, say at ten A.M. and is found to be 55.4. At eleven A.M., after taking readings at several stations and returning to the base, it is 54.9. If the sensitivity is twenty three gammas per scale division, evidently the field decreased:

$$(0.5) \times (23) = 11 \frac{1}{2} \text{ gammas.}$$

At twelve noon, the value was back to 55.4 and at one P.M. it was 56.0 or 14 gammas above what it was in the beginning. These are plotted as in Fig. 15-2.

Assume that readings had been made at stations at 10:20, 10:40, 11:20, 11:40, 12:20, and 12:40. The diurnal variation corrections for these times, as taken from the chart are plus three, plus eight, plus eight, plus three, minus five, and minus ten gammas. Applying these corrections to the readings makes all the readings correct with respect to each other for that day. When the whole survey is done, each day's readings must be adjusted so that they are all correct with respect to each other for the whole time of the survey. This is done by correcting each reading in a particular day by an amount which will make the field at the base station the same as it was the first day, 2500 gammas. If, when this is done, there are still small discrepancies between readings made at different times at the same station, small adjustments can be made so that they are the same and the intervening readings also corrected. This adjustment is usually small and arises from the fact that diurnal variation is not a simple straight line as plotted between hourly observations.

If a second magnetometer with a recorder is located at the base station, it is only necessary to pick the correction off of the record and add or subtract it from the reading for that time. Surveys made very close to a magnetic observatory (Sitka, College, or Barrow) do not need a record of diurnal variation, as this is kept at each of these places and can be taken from their records if proper arrangements are made.

When the lines and stations are laid out, a map is made of the survey area. The details of this map are filled in by the note taker. As the stations are occupied, the magnetic data are plotted on this map. If enough data are available, they may be plotted as contours of equal magnetic strength, which, in case of a buried structure, might give its shape and position. Thus, if a low vertical magnetic attraction (a magnetic "low") is observed over the channel of a creek, low value contours indicate the channel. If "highs" are encountered over a shallow magnetic placer, elongated high value contours are found over the placer.

Another way of plotting results is to draw profiles along the lines at right angles to the strike of the body sought. The theoretical shapes of the profile over several different ideal buried magnetic bodies have been worked out. These same shapes, however, may result from any one of several buried bodies of structures, and it is necessary that enough geological evidence be on hand so that some idea of the shape, orientation, and magnetic characteristics of the body sought are known. A magnetometric survey, like any type of geophysical survey is chiefly a tool to augment the geological information.

A shallow placer containing magnetite is indicated by a magnetic high directly over the placer. Similarly a vertical or dipping sulfide bearing vein may have a "high" directly over the shallowest part, but because of the dipping vein the profile of magnetic attraction will be unsymmetrical.

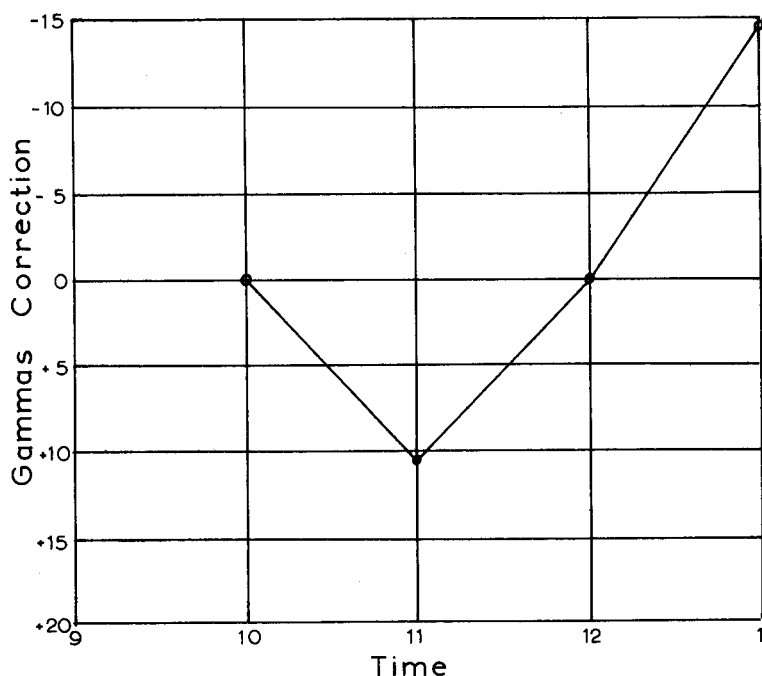


Fig. 15-2 - Correcting Magnetometric Values for Diurnal Variation

Although the magnetometer can be used to determine the depth to a magnetic body, the process is lengthy and unsatisfactory. One method involves measuring both the vertical and horizontal components and computing the magnitude and direction of the resultants, which should point to an area somewhat lower than the true depth; determining how much lower is a matter of experience. Another method is to take readings on the ground and on an elevated platform. A third method utilizes the shape of the anomaly curve (see general references at end of chapter). In general, however, if depth measurements are required, it is more satisfactory to use seismic methods.

Electrical

Electrical methods are divided into two groups: those in which natural currents generated in the earth (Earth currents) are measured, and those in which some electrical characteristic of the ground is measured while a current or electromagnetic force is being passed through the earth.

The equipment used in the methods which utilize only direct current electricity is probably the least expensive of any geophysical equipment; that with which electromagnetic forces are generated may be costly. One direct method utilizing radio waves which are sent into the earth costs approximately \$5000.

SELF POTENTIAL - The simplest electrical method, called the self potential method, measures natural earth currents. It has been used to locate sulfide ore bodies undergoing oxidation. The upper portions of such a body are more active chemically, due to the greater amount of oxygen available, and this difference in activity causes potential or voltage differences to exist. Since the ore body is a better conductor than the surrounding rock, the current generated by the potential difference flows from one end to the other, presumably from top to bottom, and then spreads out into the earth and returns to the top. Fig. 15-3 shows the current flow at an ideal deposit. A microammeter or sensitive galvanometer, attached to about 100 feet of wire with a probe at each end, is used to trace the currents. If metal probes are used, relatively large currents are generated by chemical action between probe and ground, currents large enough to mask most natural currents being sought. For this reason, the electrodes used must be non polarizing. A porous, unglazed earthenware pot is partly filled with saturated copper sulfate solu-

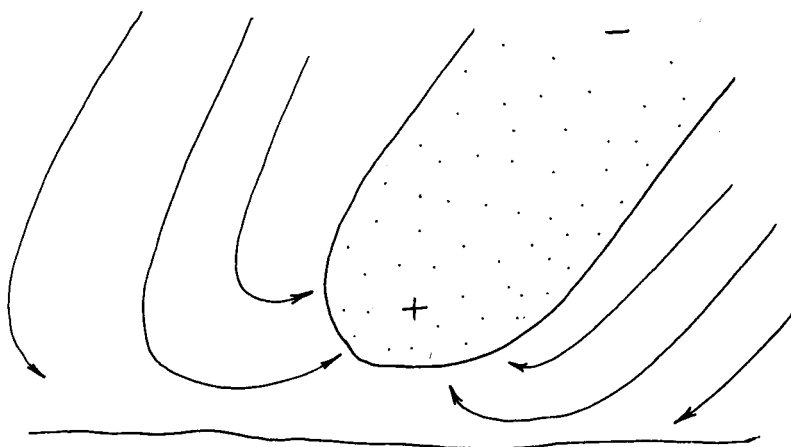


Fig. 15-3 - Natural Earth Currents Around a Sulfide Body

tion, a copper plate is immersed in this solution, and a copper conductor from the plate is led through a cork in the top and to a terminal. These electrodes are pressed firmly into the ground, which is watered if necessary to provide a good contact.

A self potential survey is conducted by choosing a straight line across the area where the deposit is suspected and setting the pots 100 feet (or fifty feet if more detail is desired) apart, near one end of the line. They are connected through the microammeter, and the current is read. The electrodes are moved to the next position, the current noted, and the process repeated until the entire line has been traversed. If a body is generating earth currents somewhere along the line, at a point directly over it the direction of the current should reverse. Surveys of such types sometimes detect small readings of variable sign until the point directly over the deposit is reached, at which time the currents become much larger and reversed in sign. As the survey gets farther and farther away from the body on the other side, the readings again become small and erratic.

Even though polarization effects are eliminated by using porous pot electrodes, the variation in resistance between the electrodes and the ground sometimes makes this method useless except when the currents involved are large.

An instrument more sensitive than the microammeter is the potentiometer, an arrangement of variable resistors, batteries, and galvanometer which measures very small differences in voltage. Such an instrument is used with the two electrodes as is the microammeter and indicates voltage drop and direction. Results are interpreted the same as when the microammeter is used.

Another way of using the potentiometer is to plot equipotential lines. One electrode is planted, and the other moved around until a point is found where the voltage drop is zero. The two electrodes then are on a line of equal potential. The first point is marked with a stake and the first electrode moved forward until another point on the equipotential line is found. If a sulfide body exists, the equipotential lines should be closed curves, with the body at the center.

IMPRESSED POTENTIAL METHODS - There are also several methods in which an electrical potential is impressed on the earth and measurements made of the current's behavior.

Parallel wire - One of the simplest such methods is the parallel wire method. Two bare copper wires several hundred or thousand feet long are laid out parallel to each other about 2000 feet apart and staked down with steel pegs every 100 feet. A 500 cycle generator is connected across the ends of the wires. Equipotential lines, more or less parallel to the wires, are traced with prodders, wooden sticks with steel spikes on their ends to which are welded bare copper wires. The wires on the prodders are connected together by a 100 foot insulated wire with a set of earphones in the circuit. When the prods are not on the equipotential line, a hum is heard on the phones. When they are on such a line, no hum is heard (a null). Due to the extremely small current in the ground, it may be necessary to use a small audio amplifier with the phones. Several equipotential lines are traced out between the wires.

These lines are plotted on a map, and since current flows across them at right angles, the current flow lines can be drawn in. If the body sought is more conducting than the surroundings, the current lines converge upon entering them, and diverge again upon leaving. If less con-

ducting, the opposite is observed. This method is sometimes employed using two points instead of two lines. Each point consists of several stakes driven into the ground and wired together. The current from one point to the other, or from one line to the other, passes into the earth and follows a curved path.

Resistivity - The methods which measure the resistivity or resistance per cubic centimeter of the earth are useful, because in addition to measuring resistance (from potential drop) it is sometimes possible to determine depths to structures or mineral deposits. There are several different arrangements of electrodes in these methods, but here only one is described.

Two current electrodes of stainless steel are driven into the ground and watered, if necessary, to make a good contact. Batteries are connected across these electrodes and a milliammeter inserted in the circuit. In a perfectly homogeneous medium, which may be approached but never realized in nature, the current flows from one electrode to the other by curved paths, which, taken together, form a hemispherical figure in the earth. The equipotential lines on the surface are roughly circular around each stake, and the equipotential surfaces in the earth are bowls approximating hemispheres around each stake. The equipotential surface midway between the stakes is a plane. In nature, of course, these surfaces deviate considerably from the ideal.

In Fig. 15-4, C_1 and C_2 are the stainless steel current electrodes connected to batteries. The current is read on a milliammeter and controlled by a rheostat and switches which can switch in more batteries as they are needed. If the equipotential bowls are considered to be more or less hemispherical, any measurement of resistivity of the material between P_2 and P_1 , the center, is influenced by material at the bottom of the equipotential bowl, and this will be at a depth equal to the distance between C_1 and P_2 . By controlling the spacing of the electrodes, therefore, the average resistivity of the material to different depths is measured. This method works best in locating horizontal bodies or contacts between materials of different resistance, such as bedrock, different beds, the water table, etc. In practice C_1P_1 equals P_2P_2 equals P_1C_2 . The potential drop from P_2 to P_1 , and from P_1 to P_3 are measured, first with the current passing in one direction, and then in another to eliminate the effect of natural earth currents. This can be considered as a measurement of the potential drop between the equipotential spheres and the equipoten-

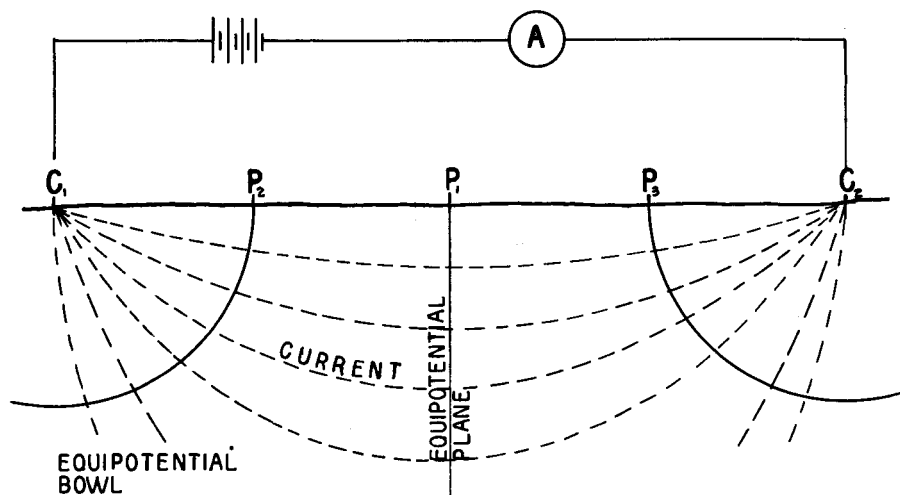


Fig. 15-4 - Three Electrode Resistivity Configuration

tial plane in the center. From these potential drops the average resistivity of the ground between the spheres and the plane can be calculated as follows. P equals the resistivity in ohms per cu. cm., A equals the separation distance in centimeters from current electrode to the nearest potential electrode (corresponding approximately to depth of penetration), E equals potential in volts, and I equals current in amperes. Then, for the three-pot configuration shown,

$$P = 4\pi A \frac{E}{I}$$

Since all measurements are in feet, A in feet must be multiplied by 30.48 to obtain centimeters. $4\pi A$ then becomes

$$(4)(3.1416)(30.48)A = 415 A$$

E and I must be measured in equivalent units, usually millivolts and milliamps. When the central pot is omitted, as it sometimes is, the formula becomes

$$P = 2\pi A \frac{E}{I}$$

As the spacing between the current electrodes and the potential electrodes is increased, the depth to which the equipotential bowls penetrate increases. Suppose that the survey is started with a spacing of five feet, and continues, the spacing being increased by five foot increments. In homogeneous ground, the resistivity increases gradually as the spacing is increased. If a bed of low resistivity lies at thirty two feet, it will short circuit the equipotential bowls at the next electrode spacing (thirty five feet). The average resistivity, of course, is affected not only by the short circuiting layer, which may be salt water or an iron or sulfide bearing layer, but also by the higher resistivity material above it. The resistivity obtained for that spacing then, probably will be little affected by the new conducting layer. There should, however, at least be a flattening off in the rate of increase in resistivity with depth. If the layer persists in depth, the average resistivity may actually decrease. Conversely, a layer of insulating, low resistivity material at depth will cause a sharp increase in the apparent resistivity at the electrode spacing corresponding to that depth.

Sometimes the effect of a change in resistivity can be detected by plotting electrode spacing, not against average resistivity but against the cumulative sum of all the resistivities for all the preceding spacings. Then a change in resistivity at a particular depth will show up as a change in slope of the curve.

The greater the amount of overburden covering the layer or contact, the greater the amount of masking of the effect of the layer by the overburden. For this reason, the method is limited to the investigation of deposits or structures buried only a few hundred feet deep, and, of course, works best at the shallower depths. Also, this method is most effective in discovering contacts between materials differing greatly in resistivity. For this reason, it is quite successful in finding contacts between frozen ground which has a very high resistivity and thawed ground.

So far the method has been described for determining the depth to a relatively horizontal formation. The variation in the average resistivity of the ground to a particular depth as the ground is traversed laterally can be determined in the following manner. The spacing is set for a 20 foot penetration, for instance, and a reading taken. The whole arrangement is then moved along a line, perhaps 50 feet, and the readings taken again. Moves of 50 feet are repeated until the region to be traversed is crossed. Any structure or deposit reaching to within twenty feet of the surface is indicated by the resistivity at that point.

Usually there is a smooth variation in resistivity with depth, making it difficult or impossible to determine the depths to contacts between layers of different resistivity. For these cases, theoretical curves showing the variation of resistivity with depth (or electrode separation) have been worked out for two and for three layers, assuming different resistivities for the different layers. The theoretical curves are plotted on celluloid, and the data found in the field are plotted at the same scale (the logarithms of the numbers, rather than the numbers themselves are used). The celluloid is placed over the paper on which is drawn the curve of values found in the field, and it is adjusted until a position is found where a theoretical curve coincides (so well as possible) with the experimental curve. A line on the celluloid indicates the depth of the boundary. The three layer problem is similarly solved. There is another method in which the curve does not need to be drawn to scale, which is described in the general references at the end of this chapter. These are procedures based upon the assumption that the different media are perfectly homogeneous horizontally and large in horizontal extent, and accurate results should not be expected unless these assumptions are justified. In practice the approximation can be quite poor.

Electromagnetic

Electromagnetic methods use electromagnetic fields, varying in frequency from ordinary alternating current of a hundred cycles or so to low radio frequencies. Such a field is either in-

duced in the ground by a radiating loop or wires or is introduced through electrodes. The higher frequency signals attenuate with depth faster than those of low frequencies; about 500 cycles per second is the frequency most used.

The electromagnetic field, on striking a conducting body such as a sulfide deposit, induces another alternating current in it. The radiation from this body distorts the original field, and this distortion can be determined by measuring the strength and orientation of the field at different points. The measuring device consists of a search coil of several hundred turns of insulated wire which can be moved in the horizontal and vertical planes, and which is connected to an amplifier and phones, or meters. The method is restricted to shallow (few hundred feet) depths.

Perhaps the fastest and most satisfactory use of this method is the search for buried conductors at shallow depth with horizontal loops. The mine detector, used to locate land mines by the army, is an application of this method.

Radiometric

With the advent of atomic energy, the search for uranium took on much more importance than previously. As a result, field instruments for measuring radioactivity were developed, and techniques for their use quickly worked out. These instruments and techniques are relatively simple, but their use requires some basic knowledge of what is being sought and what is being measured.

Elements are the fundamental materials of nature, the smallest subdivision into which materials can be broken by ordinary chemical means. These elements are composed of smaller particles—electrons, protons, neutrons and many others. The difference in the number of these smaller particles gives the different elements their peculiar characteristics. In nature, there are fifteen substances in the so called "uranium series". Some of these are separate elements, and some are different forms of the same element; that is, they have the same atomic number but different atomic weights. These different forms of the same element are called isotopes. Starting with uranium, which is the heaviest element in nature, the series drops down through the fifteen elements and isotopes to lead, and in nature, there actually is a constant transformation of part of each of the first fourteen substances to the next lowest in the series. This is accomplished by the giving up of some of the protons or electrons, which come off as alpha particles or beta particles. The loss of an alpha particle, which is a charged helium atom, atomic weight four, causes a new element, of an atomic weight of four less, to form from the emitting element. The emission of a beta particle, on the other hand, does not affect the atomic weight but changes the atomic number, creating a new element with the same atomic weight. Beta particles are electrons, practically weightless. Gamma rays, the third type of emission, are not particles at all, but waves emitted by the atom. Alpha particles can pass through only a few inches of air and are stopped by an appreciable thickness of solid. The gamma rays are the useful radiation in prospecting. They can penetrate three inches of lead, one foot of rock, two and a half feet of water, or several hundred feet of air. The steady emission of any of these three particles or waves constitutes radioactivity.

Pure uranium, at the top of the series, gives off only alpha particles, as do many of the others in the series. Others emit only beta particles. Five of them, however, also generate gamma rays. It takes each of the radioactive substances in the series a definite amount of time to be converted to the next lowest; this time is measured in terms of how long it takes for half of it to be converted and is called the half life. Newly purified uranium gives off only alpha particles for some time, until enough of the next substance, thorium, is formed to begin giving off beta and gamma rays. More time is required until the next, protactinium, is formed, and so on through the series. When finally all fifteen substances are present and the first fourteen are emitting, the uranium series is said to be in equilibrium; it takes about one million years for equilibrium to be reached. Since the earth is much older than that, it would be expected that all uranium is in equilibrium. However, weathering, which removes some substances in solution; disintegration, which causes a mechanical separation; or the migration of radon, a gaseous member of the series, may cause increased or decreased radioactivity. In the continental United States and Canada, and presumably in Alaska, most deposits are in equilibrium. Lack of equilibrium is of most concern to the prospector who wishes to use radioactivity for estimating the tenor of his ore; it usually will not prevent a deposit from being discovered.

Radiometric prospecting techniques are based on the detection of radioactivity. However, the earth is constantly being exposed to rays—extremely penetrating rays—from outer spaces and these cosmic rays affect the instruments used in the same way that gamma rays do. Also ordinary rocks, in fact all materials, contain amounts of slightly radioactive substances not connected with the uranium series. (There are other radioactive series, the most important of which are those of thorium and potassium). Radioactive thorium is a little less than half as radioactive as uranium, and potassium is very much less. For these reasons, the background count, or the level of radiation normal for the locality, and not due to a deposit of radioactive material, must be determined. This background count is then subtracted from the count in the vicinity of a deposit.

The simplest method of detecting radioactivity is to use a fast photographic film. The film is

wrapped in lightproof paper, a key or other object of distinctive shape is laid on it, and the sample over the key. If radioactive elements are present, a fogging of the film around the key is observed. For low grade materials this might take several weeks and then only produce a slight darkening of the film. A faster method uses the electroscope. This consists of two pieces of thin metal foil fastened to a piece of metal, the whole mounted in a glass vessel with only the end of the metal protruding. The metal is charged with static by touching it with a piece of hard rubber or sealing wax which has been rubbed with cloth. The like charges cause the foil leaves to fly apart. Gamma rays have the power to ionize the gas in the electroscope by knocking off electrons from the gas molecules. This ionized gas conducts a current and gradually allows the charge to leak off of the two pieces of foil, which collapse. The rate of collapse of the leaves is a measure of radioactivity.

This device is too crude and fragile for a field instrument; most prospecting is done with geiger counters. A geiger counter operates in the following manner. A glass tube (the geiger tube) is filled with some inert gas or gases such as helium, krypton, or argon. A wire, insulated from the sides, runs through the center with a cylindrical electrode around it. A charge is maintained between the electrodes just short of that which will allow spontaneous discharge to occur between them. This is about 1000 volts. When the tube is brought near a radioactive substance, the alpha particles are stopped by the glass, a few beta particles get through, but the gamma rays easily enter and leave. From one half to one percent of these strike gas molecules, which are ionized by losing one or more electrons. The electrons and ions are conductors and lower the resistance so that a discharge occurs.

The tube is attached to a box in which are housed the batteries and which contains an amplifier and some form of indicator. The amplifier amplifies each discharge, which is heard as a click in the headphones, or seen as a flash in a neon light or as a reading on a millimeter calibrated in units of radiation (milliroentgens). Those instruments which use a meter have an integrating circuit which smooths out the pulses into a steady current. If this is done so that the current holds steady, the instrument is sluggish in its response to changing radioactivity, and it is said to have a long time-constant. If it is designed with a short time-constant, the instrument responds quickly to changes but the needle fluctuates widely. Most integrating circuits are designed to strike a compromise between the extremes.

Since about only one percent of the gamma rays reaching a geiger counter are detected, inherently the geiger counter is insensitive, and no amount of additional amplifying circuits can improve it. For this reason the scintillometer, based on a different principle, has been developed, and although it is more expensive than the geiger counter it is finding increasing use. Gamma rays and beta particles have the property of producing momentary flashes of light when they strike crystals of certain compounds, e.g., sodium iodide or potassium iodide, called phosphors. The light from these flashes is eventually connected to a current, the current generated is amplified, smoothed out, and taken to an indicating meter. Since over 50% of the gamma rays penetrating the crystal produces a flash of light, this instrument is much more sensitive than the geiger counter. However, the type of instrument cannot alter the behavior of the particles and rays. Gamma rays are still stopped by a foot of rock or several hundred feet of air; the scintillometer merely detects more of those that get to the instrument.

Prospecting with a Geiger counter or scintillometer is basically the same as any other prospecting. First, the literature and knowledge of experienced men are sought to choose the likeliest areas to prospect; then the area is subjected to a reconnaissance to see if any surface indications are picked up, then the smaller area chosen is prospected and explored in detail. When prospecting for placer gold, an area containing fine colors may be the target in which the detailed work is done; when prospecting for uranium, an area of a few times background count is the initial target.

Until now, only one area in Alaska that contains uranium in paying amounts has been discovered. This is on the southeastern part of Prince of Wales Island. The deposit was found by aerial reconnaissance, using an airborne scintillometer, in an area where uranium was not previously known to exist. Use of the airborne scintillometer is the only practical method of reconnaissance in Alaska; ground methods are too slow. There are, however, a few areas which show slightly greater promise than the average. These have been delineated by the U. S. Geological Survey, which has investigated every locality where radioactive minerals have been found in placer concentrates. In general, the Chandalar-Romanzof Mountains area of the Arctic is thought to be one such area, because the rocks of the area and the concentrates of the creeks are slightly more radioactive than those elsewhere. The Brooks Mountain (not Brooks Range) area near the western end of the Seward Peninsula contains a low grade deposit of zeunerite or meta-zeunerite. In addition to these areas, slight indications have been found in the Manley-Rampart area, the Aniak area, the Yakatoga area, the Flat area, and the Northeast Seward Peninsula. Although a prospector is not justified in spending much time or money searching on the ground in Alaska for uranium by itself, a geiger counter should be taken along on any prospecting trips.

Before starting any survey, either reconnaissance or detailed, the instrument should be calibrated. This is done by obtaining a sample of known uranium content, crushing it, and taking

a constant amount (a coffee can full). The tube is laid upon the ore, and the whole shielded as well as possible with sheet lead. The counts per minute are noted, and the procedure is repeated with ores of different concentrations. A graph is drawn showing percent U_3O_8 (uranium assays are expressed in terms of the oxide) plotted against counts per minute or other indication. See Fig. 15-5. Percent U_3O_8 can then be read directly from the graph, but only when a crushed sample of the same volume, the same distance from the tube, and with the same shielding is used. It should be noted that the radiometric assay can only express percent U_3O_8 when radiation is caused by uranium. Radiation due to thorium or even potassium gives a reading equivalent to a particular U_3O_8 percentage. For this reason, percentages found by radiometric assays are expressed as " U_3O_8 equiv.", " U_3O_8 rad.", or " U_3O_8 e.". When the prospector travels, he should take readings whenever he stops, laying the counter tube against the bedrock or overburden. If no significant variation is noted during the reconnaissance, it is fairly safe to assume that the area is unfavorable for uranium. However, if an area consistently gives a reading of two or three times the background count, it should be laid out in a grid network from twenty to several hundred feet on a side, and the corners of the grids systematically occupied. Each reading should take several minutes because the accuracy of the observation increases as more time is taken. (A scintillometer responding to many times more gamma rays than the Geiger counter, of course, requires less time). The readings obtained during the reconnaissance are averaged together to get the background count. From each reading the background count is subtracted, and the remainder is the anomaly. The anomaly is often expressed as the ratio of the counter reading to the background. The anomalies, or the total counts, should be plotted on a map of the grid network and contours of equal anomalies or radioactivity should be drawn. If an area of definitely high activity is found, samples should be taken and assayed with the counter.

What are some of the factors that can make the results of such an assay unreliable? It has already been noted that uranium may be out of equilibrium; such a condition produces the equilibrium effect. Closely allied to this is the radon effect. Radon, a gas, is not a gamma ray emitter; however it has a short half life, and the succeeding members of the series have short half lives. This leads to the rapid formation of a strong gamma ray emitter. Since radon is a gas, it can migrate and become trapped to build up an abnormally high concentration. Such a concentration, which might be encountered in freshly broken rock or in underground workings, gives an abnormally high reading. Radioactivity due to thorium (thorium effect) may produce erroneous results. Laboratory scintillometers can now differentiate between the radiations of members of the uranium series and those of the thorium series.

The mass effect is the influence of size of deposit upon the behavior of a counter. Large bodies produce a higher reading than small bodies or ore of comparable grade. It can be eliminated by following the assaying procedure already outlined. The cosmic effect is the contribution of cosmic rays to the meter readings. It is considered as part of the background count. The topographic effect is that which causes variations in readings with variations in topography. If cosmic rays account for a large proportion of the reading, taking the instrument into a gully or a mine where it is shielded produces a decrease in the reading. If, on the other hand, a large proportion of the radiation is coming from the rocks, the reading will increase in such places. The absorption or cover effect is the decrease in readings because of a covering of water or overburden. If soil is more than two feet thick, the radioactivity being measured is coming from the soil, not the underlying rock. This does not preclude discoveries being made through the overburden, because if the soil is a product of the weathering of the rock beneath, some of the radioactive materials may be in the soil. Drift or other alluvium which has no relationship to the underlying rocks, of course, make prospecting with the counter more difficult and misleading. After a radioactive area has been outlined by the counter, prospecting procedures are the same as for any other lode deposit. Pits or trenches are sunk, samples taken and assayed with the counter, and sent in for chemical analysis. The radioactivity may have been caused

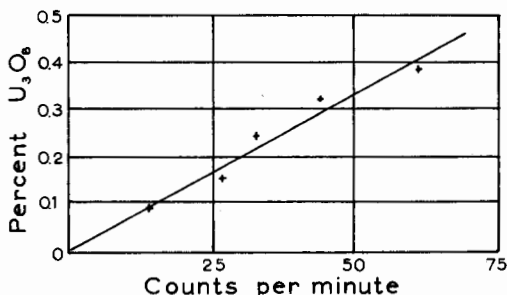


Fig. 15-5.- Percent U_3O_8 Plotted Against Counts Per Minute. This Chart Only Illustrates the Type of Measurements to be Made. It is not Intended to be Used for Assaying.

by a pegmatite dike containing radioactive potassium, by thorium, or by uranium ore; conventional methods of prospecting and analysis must be used to determine which one was responsible.

Ultraviolet Light

This method takes advantage of the excitation of the molecules of certain minerals by artificially produced ultraviolet light. It is different from other geophysical methods in that it does not measure a physical quantity, from which the presence of ore may be inferred, but makes the ore actually visible. Visible light varies from red, the longest wave length color, to violet, the shortest. Longer waves than those which create the impression of red upon our eyes are heat waves, called infra-red waves. Waves of shorter length than those which create the impression of violet are invisible, and are called ultraviolet waves.

These ultraviolet waves have certain characteristics. Among others, they kill germs and often tan human skin. Of course the waves which we call "ultraviolet" cover a wide range of wave lengths; therefore there are "long" ultraviolet and "short" ultraviolet waves. If ultraviolet light of the right wave length strikes certain minerals, part of its energy is used in displacing some of the electrons of the atoms in the mineral. Upon dropping back into its original position, the electron re-radiates a portion of the energy it received, and if the radiation falls within the limits of visible light, it can be seen. Minerals possessing this characteristic are said to be fluorescent. If they continue to glow after the source of ultraviolet light has been removed, they are said to be phosphorescent.

There are many minerals which fluoresce under ultraviolet light of one wave length or another, and there are also many minerals which fluoresce when they contain certain impurities in the correct proportion. Such impurities are called activators. Thus, most calcite will not fluoresce, but that from certain localities containing from one to five percent manganese does. Again, scheelite will not fluoresce under long wave ultraviolet light but fluoresces strongly under short wave ultraviolet light.

Scheelite is probably the only mineral that the prospector is likely to be searching for exclusively with an ultraviolet light, although the instrument can be used, if available, to identify certain other minerals which might turn up in the course of prospecting. Such minerals might be willemite and sphalerite from certain localities.

In most of Alaska there are only about two months in which the ultraviolet lamp can be used outdoors without the use of a canvas to keep out the light. This is from the middle of August, when the nights begin getting dark, until the middle of October when the first snow usually falls. Underground, of course, the light can be used at all times. During the summer a canvas or blanket can be used at night when the sun is not shining brightly.

The ultraviolet light is not used as other geophysical devices; that is, on the corners of grids or on lines at right angles to the strike of the deposit. Since it is actually an aid to seeing, it is used to make detailed examinations of all exposures. As a reconnaissance tool it is used at night (in the fall) to examine cut banks along roads and streams or rock outcrops in a likely area. During prospecting, exploration, or development it is used to examine all open cuts or underground workings. It is also used as an identification instrument and for roughly determining the amount of mineral in ore brought into camp. Some instruments have been built with a light box on the end; the sample is placed in the box and examined under ultraviolet light in the daylight. Such a device has the advantage of not being affected by light, but, of course, its use decreases the speed and thoroughness with which an area can be examined. Because each sample must be picked up, broken to size, put in the instrument, observed and discarded, this instrument is designed primarily as an aid to identification; not for reconnaissance.

In prospecting for scheelite, or other fluorescent minerals, the rules governing sampling and chemical analyses must be followed just as in prospecting for any other mineral, but the ultraviolet light gives the scheelite prospector a tremendous advantage in that he knows before the assay is made that there is scheelite present, roughly how much, and its distribution.

Induced Radioactivity Methods - The "Beryllium Meter"

Methods in which a radioactive source activates another source of radioactivity have been used in well logging for oil and water for a number of years. With the application of these general methods to the detection of beryllium they became available to mineral prospectors, also.

In the "Beryllium meter", radioactive antimony emits gamma radiation which in turn knocks neutrons from beryllium in a sample placed in the instrument. The neutrons produce light flashes on a phosphor. A photomultiplier tube and suitable amplifiers give an electrical current which is proportional to the amount of beryllium present.

Antimony 124, used as the gamma ray source, has a half life of 60 days, and its useful life is about five half lives or approximately ten months. If the instrument is calibrated at frequent intervals by noting readings produced by samples of known beryllium content, it can be used as a beryllium assaying device, accurate to about 0.25%. The procedure is identical to that de-

scribed on page 277 for uranium ore.

Because the gamma ray source must be replaced periodically, and because of the high voltage required and the bulkiness of the equipment, it is not practical to use the instrument as a reconnaissance tool. However, once a beryllium area is located, it should prove very valuable as a prospecting device and as an assaying instrument.

Conclusion

In this discussion of geophysical prospecting methods, seismic, gravimetric, magnetic, electrical, electromagnetic, radiometric, induced radiometric, and ultraviolet light techniques have been described. Of these, electrical, radiometric, and magnetic methods are better adapted to mineral prospecting than are the others. The ultraviolet light and induced radioactivity methods have a restricted use and are used mainly for identification and rough assaying.

Before leaving the subject, the applications to mineral prospecting should be reconsidered. First, geophysical methods are to be used only after a geological study has indicated a specific question or questions which it is believed geophysics may be able to answer. It is also necessary to know whether the method has a chance of providing useful results. For instance, a series of profiles of vertical magnetic attraction across a creek should indicate the position of a paystreak. However, before going to the expense of running such profiles, the prospector should have some idea of the amount of magnetite in the concentrate, the depth to bedrock, and especially whether great variations in magnetic attraction exist from place to place in the bedrock.

To aid in visualizing the possible uses to which the various methods might be put, Table 15-1 has been prepared (after Bateman and after Heiland, modified).

Table 15-1 Application of Geophysical Methods

Type of Deposit	Exemple	Geophysical Method	
		Direct	Indirect
Magmatic Concentration Disseminated in intrusives Segregated	Diamonds, Chromite Platinum, Tin Magnetite Sulfides	Magnetic Electric, Magnetic, Electromagnetic	Magnetic, Gravi- metric, Seismic
Sublimation	Sulfur	Minor	
Contact Metamorphic	Sulfides Magnetite	Electric, Electro- magnetic Magnetic	
Hydrothermal Disseminated in veins, stockworks, dikes, etc. Massive Deposits	Vanadium, Uranium Beryllium Sulfides, Gold Sulfides	Radiometric Induced radiometric Electric, Magnetic Electromagnetic Electromagnetic Electric, Magnetic	Magnetic, Gravi- metric
Sedimentation (Exclusive of Evap- oration)	Vanadium, Uranium Iron, Manganese, etc.	Radiometric	Magnetic, Seismic Gravimetric, Electric
Evaporation	Potash, Salt, Gypsum, etc.		Magnetic, Electric Seismic, Gravimetric
Residual	Nickel, Iron, etc. Gold		Magnetic, Electric Magnetic, Electric Seismic
Surface Oxidation and Supergene enrichment	Sulfides	Electric, Magnetic Electromagnetic	
Metamorphism	Talc, Asbestos		Gravimetric, Seismic

GEOCHEMICAL METHODS

Most of the geophysical methods just reviewed are indirect; it is not the concentration of mineral that is measured but some physical property which indirectly provides evidence about the location of the mineral. Unfortunately, there are usually several possible sets of circumstances which may produce the same effect upon the instruments, and the geophysical prospector must supplement his observations with a great deal of geological evidence before the geophysical data have meaning.

In the oil industry, where large structures are being sought, the indirect methods have been eminently successful, because, given an area of favorable reservoir rocks of the right age, it is only necessary to drill on the structural traps to test whether oil occurs or not. Structural traps can be outlined accurately by geophysical means.

In the search for minerals, however, conditions are different. Very large deposits of magnetite or uranium can be outlined successfully by their respective properties of magnetism and radioactivity, but what method could be used to outline a large lowgrade copper deposit, averaging less than one percent copper? Possibly some electrical or electromagnetic method might prove applicable to such outlining after the deposit has been discovered, but it is doubtful if there is any geophysical method which would aid in the discovery of such a deposit. Small deposits such as narrow gold veins are likewise difficult to find or trace by geophysical means.

It has long been known that mineral deposits have a "halo" surrounding themselves, in which the concentration of the minerals present in the deposit is, although very low, well above the average for the surrounding rocks and such unconsolidated material. Minute amounts of metals are called "trace amounts". The halo may be primary, meaning that it was formed at the same time as the mineral deposit itself by the same agencies which created the mineral deposit. Primary halos are found in rock surrounding ore deposits.

The halo, on the other hand, may be secondary; a space around the deposit in which water or unconsolidated material gradually acquires quantities of some or all of the heavy metals occurring in the ore deposit.

These secondary halos are useful for reconnaissance geochemical prospecting such as will be discussed here; primary halos may be of great value in prospecting for blind ore bodies underground. For the rest of this discussion, "halo" will refer to a secondary halo.

Sometimes the halo is peculiarly shaped because of hillside creep, and sometimes it may be missing altogether because of rapid erosion by water or ice and subsequent refilling by material in which even minute quantities of minerals have not had time to accumulate. Usually, however, the halo is present. The halo is several times as large as the deposit causing it and consequently, much easier to locate if some means can be devised for identifying it. The halo and the mineral deposit causing it may be called the "target". Formerly, samples taken in the halo could be analyzed in a chemical laboratory, where the minerals were identified and expressed as a percentage or, if in very low concentrations, as "parts per million", p.p.m., or "parts per billion", p.p.b.

Recently, fast, simple methods of analyzing soil, water and vegetation for their heavy metal content have been developed, many of which can be used in the field or in a simple laboratory set up in any cabin. Many organizations and individuals have been responsible for the development of these methods; the methods which are described here have been developed by the U. S. Geological Survey and the University of Alaska.

There are two broad classifications of geochemical prospecting methods: the general method and the specific method. Each has its fields of application; the general method, fast and simple, is most valuable for reconnaissance prospecting of most deposits, while the specific method is most valuable for more detailed exploration of known deposits. The foregoing statement was qualified to read "of most deposits", because the general method depends for its effectiveness upon the presence of heavy metals, zinc, lead, or copper principally. At least one of these is found to some extent as an accompanying mineral in most metalliferous deposits and therefore may be traced back to the deposit just as the actual ore mineral might be. Zinc is the most useful of these indicator elements or metals because it is the most soluble of the three and therefore will migrate farthest from the mineral deposit and produce the largest halo. The minerals are dissolved by the weak acids present in the ground water. Studies of ore deposits indicate that the presence of carbonate rock (chiefly limestone) hinders the migration of most metals. It has been stressed many times that all methods of prospecting are basically alike, and geochemical prospecting is no exception. In Chapter 9 a method was described in which the prospector takes pans of dirt at intervals along a stream and examines the heavy mineral concentrate to note any large percentages of any particular mineral. The equivalent of this in reconnaissance geochemical prospecting is to take water samples at intervals along a stream, noting any increase or decrease in the concentration of heavy metals. This analysis is performed almost as fast as the samples can be taken. Another method described earlier is the sinking of drill holes or auger holes at regular intervals across a vein or mineralized zone. Samples so obtained are analyzed by panning or by wet or fire assay. In geochemical prospecting, this method consists of drilling small auger holes at regular intervals across a suspected ore body or mineralized zone. A hand

auger which can be disassembled for easy transportation can be used. A small sample is taken from the bottom of the hole and analyzed at camp by methods to be described.

Sampling of Water

Water which passes through a mineralized zone has a higher metal content than normal for the area. As this water flows away from the mineral deposit its drainage pattern constitutes a widespread halo. If the water is flowing in a stream, the direction to the deposit can be determined easily by following upstream, taking samples at intervals. Sampling of water is more of a reconnaissance method than is soil sampling.

Water samples are taken in a graduated glass cylinder from just under the surface of the fast flowing part of the stream (preferably the fastest if accessible), away from shore and vegetation. They may be taken around the shores of a lake or from ground water. Lake samples should be taken a few feet from shore and away from vegetation.

The water container should be washed several times in the water to be tested before samples are taken. The method depends on the fact that the water, percolating through areas of mineralization, has dissolved and carried heavy metals from the deposit. Snow or heavy rain runoff may dilute the stream or lake water to such an extent that the method is not applicable. Times of low water are therefore the best for this method.

The shape of the halo in water is always elongated in the direction of water flow. Therefore, it is necessary to sample the water upstream until the metal concentration is found to decrease suddenly. Samples should be collected at intervals, testing all tributaries along the way. As in all prospecting, a sketch map of the locality should be made, on which results are plotted. A falling off of values above an area along the stream indicates that the trace amount of metals are coming from that area. When sampling a stream, it is necessary to remember that water issuing from an abandoned mine may show high metal concentration of heavy metals and may interfere with the concentration pattern of the target area. The mine may be completely worked out, yet the channeling effect of the opening brings the water into contact with enough mineralization to contaminate the water downstream and mask any anomalies due to an undiscovered deposit in the catchment basin. If sampling proceeds downstream, a sharp increase in heavy metal content at any point means that water from a mineralized area is entering the stream at that point.

The location of deposits by sampling lake or ground water is more difficult than it is by sampling stream water. The direction of seepage of lake or groundwater sometimes is hard to determine, and usually it is difficult to obtain enough groundwater samples to adequately outline the halo. The water which causes a high reading along a particular segment of lake shore almost always is ground water entering at that point, and it must be traced back from shore by ground water sampling methods. The shape of a groundwater halo of a deposit tends to be fan shaped, expanding away from the deposit in a downslope direction. If no movement of groundwater is taking place, the halo is circular or elliptical, but perfectly stagnant groundwater is very unusual.

The presence of organic material or fine solids in the water makes the determinations less positive. Sometimes taking a smaller sample is helpful, as is increasing the amount of dithionite (the function of which will be discussed presently). Organic material in water or soil absorbs heavy metals, removing them from circulation and reducing the amount available for geochemical analysis. This results in a lower reading where organic material is present.

Sampling Soil

Soil sampling is the most widely used and probably the most useful method of geochemical prospecting. The trace amounts of metal are transported into the soil away from the source in a number of ways and are disseminated throughout the halo. In ordinary sampling, holes must be driven to and into bedrock and the samples analyzed; in geochemical prospecting the holes need not extend to bedrock.

For the purpose of geochemical prospecting, soil is considered to be the unconsolidated material above bedrock. The residual product of disintegration of the underlying bedrock is the best soil for geochemical prospecting. If the soil has been transported to its present resting place by fluvial, glacial, or eolian processes, it may not necessarily reflect an ore body below. If the transported mantle has been in place for a long time, trace amounts of metal may work up by a combination of dispersion, frost heaving, and solution; hence a halo may be formed, which can be detected by geochemical means. If the soil has been transported and emplaced only recently, of course, it effectively masks any underlying targets. However, in recently transported soils a halo may be present, located close to bedrock; samples must be taken from deep holes to detect it.

In taking soil samples, experiments during the early stages of work in a particular area should be made to determine what is the best level to sample. A "soil profile" is the change in soil from the surface down to bedrock. A complete soil consists basically of three layers or horizons:

the topmost or A layer, consisting of a weathered zone of topsoil, with incorporated organic material, the B layer, an intermediate soil which has undergone some leaching, and the C layer, or parent material, which extends more or less homogeneously to bedrock. If the soil is formed of residually weathered bedrock which is the optimum for geochemical prospecting, satisfactory results might be obtained by sampling the A layer. Even though the B layer or C layer might give better results, the A layer could be sampled so quickly that it would be advantageous to do so. On the other hand, conditions might be such that the samples must be taken near the bottom of the C layer. Intermediate conditions might call for sampling the B layer. While certain soluble metals may migrate quickly to the A layer, they may be washed away by rainwater, leaving the A layer barren. Thus, zinc is able to disperse itself easily because of its high solubility, but for the same reason it may not be found in the A layer. Tungsten, on the other hand, is not so soluble as zinc, but once it reaches the surface, it resists solution and removal, and can be sampled from the A layer.

If pebbles or slide rock occur in the C layer, an auger cannot be used to obtain deep samples. In such a case the A, B, or upper C layer are utilized if possible, and if they cannot be used, samples must be obtained using some other means. Such methods include pick and shovel, post hole diggers, spoon shaped shovels, or rod and pipe. (The rod is driven ahead of the pipe, then removed through the pipe and the pipe driven an inch or so to pick up a sample).

Whatever layer is decided upon should be sampled consistently. This requires that soil from each horizon be examined until it can be identified. Samples, if very wet, are kept in plastic bags; dry or damp samples may be transported in cardboard boxes. At least five grams should be kept as a sample. All samples should be numbered and their position plotted on a map.

The shapes of halos in soils vary with conditions of slope and water flow. An ore body which crops out or reaches the top of bedrock in flat country has a more or less circular halo because there is no tendency for the metals to disperse in one direction any more than in another. On the other hand, a slight grade causes the halo to have a broad fan shape (in horizontal view) with the ore deposit at the upper point. Steeper slopes cause the fan to be sharper. If the migration is due to underground water movement, the halo is elongated greatly, and the problem is identical with that of locating a deposit by sampling ground water, as already discussed.

Sediment, such as valley alluvium, is not properly considered a soil until it has been stabilized long enough for weathering to occur. Heretofore in this discussion sediment has been considered merely a troublesome cover which can mask any underlying deposit, unless dispersion from below has had time to create a new halo. However, the possibility of trace amounts of metal having been transported and deposited as part of the sediment should not be overlooked. In such cases the sediment is an elongated halo, leading back to the source. The problem is much like that of sampling stream water.

The following tabulation lists the possible mechanisms of dispersion of elements, compounds, or ions through soils:

1. Diffusion by underground water movement, partly molecular, partly turbulent, and partly mechanical transportation.
2. Residual soil, in place or transported by hillside creep, solifluction, slope wash, rilling, or any other form of mass movement.
3. Diffusion of molecules in moist or saturated earth. The molecules are in random motion due to their molecular energy. There is a component of movements from areas of high concentration toward areas of low concentration, hence outward from the target.
4. Dispersion due to decay of vegetation which prior to decay extracted metal from deep soil into which its roots penetrated.
5. Solid to solid molecular diffusion. This is extremely slow, and it is doubtful if it can account for any appreciable migration of heavy metal in a halo. In the case of permanently frozen soils, the migration rate of metals is not known. If halos are ultimately found in permafrost, they may have been created before the soils became frozen, or they may be due to solifluction and other forms of movement associated with permafrost, which have been discussed under geomorphology.

What constitutes an anomaly depends upon the same factors as does radiometric or other geophysical prospecting. It varies from prospect to prospect because of differences in the dispersion rates of the metals sought, their abundance in nature, depth of overburden, depth from which the sample was taken, length of time dispersion has been going on, type of dispersion, concentration of metals in the deposit, and many other factors.

The anomaly, as in geophysical prospecting, consists of a difference between the concentration in the halo and that outside the halo, increasing toward the source. Because of the variable factors just named, no standard concentration in parts per million can be stated. In crosscutting a deposit by any means, whether by drill holes, shafts, magnetometer, or geochemical methods, samples or readings are taken on both sides until values are not much above those expected for the non-mineralized countryside. In geophysical or geochemical prospecting, average low reading is called the "background". In geochemical prospecting it may be necessary to sample areas

well outside the halo, or supposed halo, but usually the background concentration can be established merely by extending the lines of samples until the concentration drops off to some uniformly low value. In sampling water, it may be necessary to test several streams before a background concentration is determined; at least if it is suspected that a certain set of samples are above background concentration, other streams, or lower parts of the same stream should be sampled as a check.

In sampling soil, it is usually best to decide the highest value which will be called background; an anomaly will consist of a reading of say two or three times this value. This allows the prospector to outline areas of concentration of two or three times background count. Lines of equal concentration are then drawn on the map as contours, and the intersection of the halo with the ground surface thereby indicated. If the samples were all taken from the same layer no more need be done. If samples were taken from two layers, or two different depths of the same layer as might be necessary when the A and B layers have been removed in previous prospecting operations, two sets of contours, one set for each layer should be drawn, because the deep C layer samples usually show a greater concentration than the shallower ones.

Analysis of Samples

The methods used in geochemical prospecting for the analysis of trace amounts of metals are divided roughly into general methods and specific methods. Specific methods are used to identify and to determine the amounts of specific metals. Recently specific methods have been used for zinc, copper, lead, antimony, cobalt, manganese, molybdenum, nickel, silver, tungsten, vanadium, arsenic, barium, germanium, niobium, selenium, and titanium; no doubt this list will be augmented from time to time.

The general methods detect the total combined amounts of copper, lead, and zinc, plus a small amount of less soluble metals, without differentiating between them. As stated previously, there are generally small amounts of copper, lead, or zinc present in many ore deposits; hence the general method is applicable to the detection of deposits of many more metals than only copper, lead, or zinc.

The specific methods are useful for the exploration of lodes that do not contain copper, lead, or zinc, but they are too unwieldy for reconnaissance; for that the general methods are used. From the foregoing it is evident that for the majority of deposits the general methods are applicable, either for reconnaissance prospecting or for exploration of a known deposit. For this reason they are the most valuable, and they are described here. The prospector who may require a specific method should write to the College of Earth Sciences and Mineral Industry, University of Alaska, or to the U. S. Geological Survey, outlining the special problems.

Several procedures have been developed under the general method; all use colorimetry, that is, the identification of colors, as a basis. The dye used is an organic compound, diphenyl thiocarbazon (shortened to dithizone). The procedures given here are the latest and simplest, and have been modified from U. S. Geological Survey methods by the Research Department of the College of Earth Sciences and Mineral Industry, University of Alaska.

EQUIPMENT— The following equipment and supplies are assembled:

- 2 100 milliliter glass graduates, stoppered
- 2 32 ounce polyethylene bottles with straight cone tip
- 1 16 ounce polyethylene bottle
- 1 8 ounce polyethylene bottle, straight cone tip
- 1 8 ounce polyethylene squirt bottle with curved spout
- 1 8 ounce polyethylene squirt bottle with resin demineralizer
- 2 plastic scoops, 0.1 gram and 0.25 gram
- 0.25 gm. hole 1/4" deep, 9/32" diameter, approximately
- 0.1 gm. hole 3/16" deep, 3/16" diameter, approximately
- 1 plastic funnel
- several plastic bags
- 2 quarts white gasoline or pressure appliance fuel
- few ounces Sodium Chloride
- " " Potassium Citrate
- " " Sodium Bicarbonate
- some clean absorbent cotton
- 5 gms. dithizone
- 1 box gummed labels, grease pencil
- 1 pc. nylon stocking; 60 gauge, 15 denier
- *Hardwood charcoal may be made and powdered in the field, but it is best to purchase de-colorizing charcoal.

All equipment except the graduates are of flexible polyethylene, which has the advantage over glass of being relatively non-breakable. In addition, liquids may be forced to flow under pressure by squeezing the flexible bottles. All reagents should be kept in a dark place and refrigerated; in the field a storage place in the ground or in a stream can be improvised which

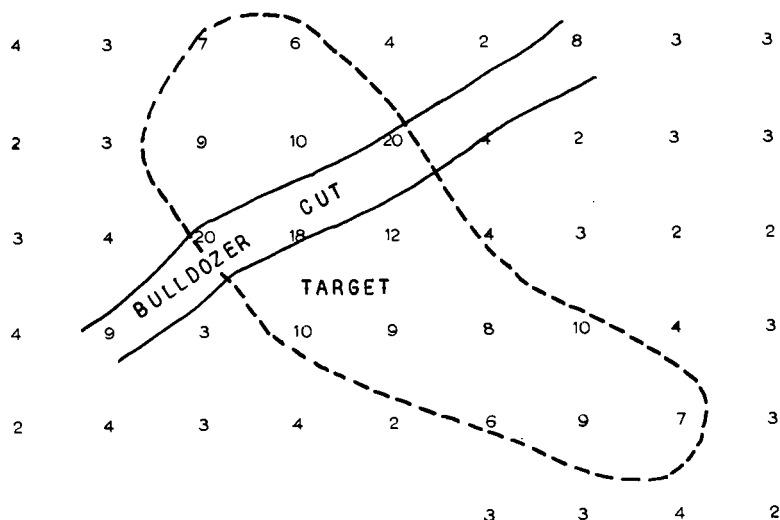
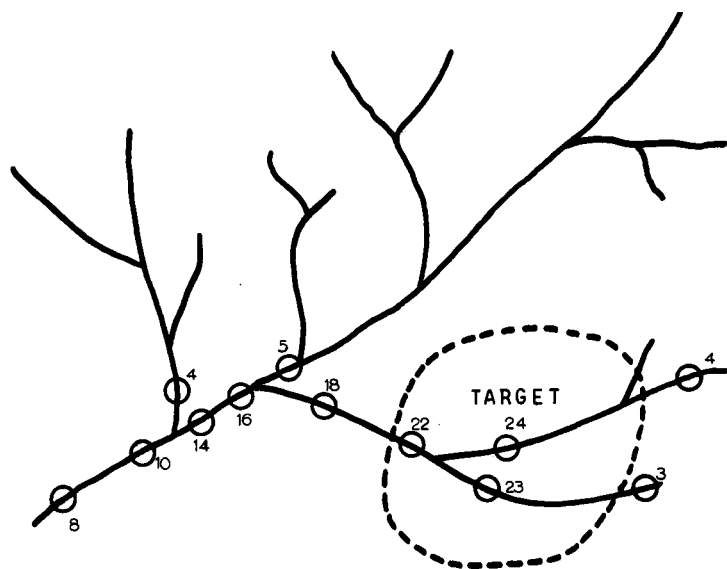


Fig. 15-6 - Water Samples Taken Along A Stream System (Top) and Soil Samples Taken on a Grid (Bottom). Values are in milliliters of dye used. Note that in bulldozer cut (bottom) values are higher, because they are taken from C Layer rather than A or B Layers.

will serve as a refrigerator.

Clean white gasoline is poured into a 32 ounce bottle, and two tablespoons of charcoal for every quart of gasoline is added. The bottle and its contents are then stoppered and shaken vigorously for three minutes and allowed to stand for ten minutes. The stopper is removed and the gasoline filtered through cotton into the other 32 ounce bottle. If the gasoline is not clear and colorless, it should be refiltered.

A saturated solution of dithizone in white gasoline is made by dropping several pieces of dithizone into the purified gasoline and shaking for fifteen minutes. At the end of this time, excess dithizone should remain in the bottom; if not, more should be added and the shaking repeated. The green-dyed gasoline is decanted into the 16 ounce bottle or the other 32 ounce bottle which has been cleaned and is then stored in a cool dark place. This dye should not be prepared more than one week in advance.

Into the eight ounce bottle are placed sodium chloride, sodium bicarbonate, and potassium citrate in these volumetric proportions: 3:1:6. (6:1:12 by weight). The bottle is rolled and shaken until the contents are thoroughly mixed. This is known as the conditioning reagent.

Rain water, snow water, "soft" lake or stream water is poured into the eight ounce bottle, and the resin demineralizer fitted to the top. Demineralized water is prepared by squeezing water through the demineralizer as needed.

The dithizone solution takes up any metal with which it comes in contact; and in so doing, it changes color. Hence it is the cleanser for the equipment as well as the indicator for metal content. The determinations are made in the 100 milliliter glass graduate, which is first cleaned with detergent and a brush, rinsed with soft water, and then with demineralized water. It is then rinsed with dithizone solution and checked for contamination by adding 1/4 gram conditioning reagent and 1 ml. dithizone dye. If, after one minute's shaking there is no color change, the graduate is clean. If the dye changes color to pink, violet, yellow, brown, or colorless, metal is present, and the graduate must be cleaned further with dye. (The glass stopper must be cleaned as well as the graduate. In shaking, the graduate is never stoppered with the thumb, which would introduce contamination, but with the glass stopper).

WATER SAMPLES - Water samples are analyzed as follows: The graduate is checked for contamination, then washed three times with the water to be tested. A 10 ml. sample is taken, and 1/4 gm. conditioning reagent added. One ml. dye is added, and the graduate is shaken vigorously for one minute. If the color changes, another ml. of dye is added, and the graduate shaken again. Dye is added by 1 ml. increments until the dye solution remains green. The first green detected will be faint. Some observers can detect fainter shades than others; any one observer is usually consistent. The amount of dye required to produce the end point (no color change) is proportional to the amount of heavy metal in the water. The position of each sample is plotted on a map, and a number, corresponding to the number of milliliters of dye used, is entered near the position.

This general method is not designed primarily for identification of the metals present. However, upon the addition of the first ml. of dye, a rough identification is possible. Copper turns the dye violet, brown, or yellow-brown; zinc, violet; and lead or other metal, pink. If the dye is oxidized, it will turn brown or yellow-brown even when metal-free water is used. If oxidation has taken place, the dye should be discarded; the gasoline may be recovered by purifying with charcoal and filtering as already described.

SOIL SAMPLES - A five gram sample of soil from the bottom of the hole is placed in a plastic sample bag, which is labeled with grease pencil. In camp the samples are dried in saucers or in small cups shaped of aluminum foil (these cups are also marked). The samples are then screened to 80 mesh (a piece of 60 gauge, 15 denier nylon stocking stretched over the end of a cardboard cylinder makes a non-metallic screen).

One-tenth gram of the screened soil is scooped up and placed in a clean metal-free graduate and one-fourth gram of conditioning reagent added. These are washed down the sides with five ml. of metal-free water. One ml. of dye is added and the cylinder is shaken for one minute. The procedure from here is the same as in the analysis of water.

It must be emphasized that oxidation of the gasoline or of the dithizone renders them unusable. Oxidation must be watched for as well as contamination; the tests are identical and performed at the same time. Dithizone, as a solid or in solution, must be stored in a dark cool place at all times.

Results of soil sampling are plotted similarly to results of water sampling. Usually, however, soil samples are taken on the corners of a grid system or in crosscuts. Figure 15-6 shows a possible set of water samples and of soil samples. Values are plotted in milliliters of dye used, which is proportional to metal content.

MINERALOGICAL PROSPECTING

In Chapter 10 a fundamental practice in prospecting was described, in which samples were panned at intervals along creeks. If traces of gold or other economic minerals are noted, a search for these minerals, either in placer or lode deposits, is made farther upstream or upslope.

Several authors have extended this procedure and have developed a method, which for want of a better name is called here "mineralogical prospecting". This is simply the panning method, extended to cover the identification of a larger number minerals from a larger area. The principle works covering this subject are "Alluvial Prospecting", by C. Raeburn and Henry B. Milner; D. Van Nostrand, N. Y., 1927; Circ. 127, U. S. Geological Survey; "Geochemical and Mineralogical Methods of Prospecting for Mineral Deposits", and some unpublished work by H. R. Joesting, made available by the Territorial Department of Mines, now the Division of Mines and Minerals, Juneau, Alaska.

The last mentioned work provides an example of the application of the method and of the results which may be obtained. Just before World War II, the Division conducted experiments with two geophysical methods to determine their applicability to prospecting in Alaska. In the course of the work, placer concentrates from many creeks were examined to determine how much magnetic material was contained; during these examinations, many of the non-magnetic minerals were noted. When the war came, attention was shifted to the search for strategic minerals, but the same procedure was used. Samples of placer concentrates were gathered, and every mineral was identified and listed in order of relative abundance. Areas which produced concentrates with a high percentage of one or more economic minerals were noted as being worthy of prospecting.

There are no new or unique techniques to learn to carry out mineralogical prospecting. Samples are taken along watercourses or slopes by accepted methods already described, and the minerals contained in the concentrates derived from the samples are all identified by standard means. Samples from bedrock are most useful, but for reconnaissance work, samples taken from shallow pits or drains are used.

The alluvium of a basin, along with the rocks which supplied and are supplying the alluvium, may be visualized as a geological unit, and the area in which they occur may be viewed as a geographical unit. Such a unit has been given the name "distributive province". The larger the distributive province, the larger the number of parent rocks and the more difficult the problem of tracing any particular economic mineral to its source. For instance, if a prospector is

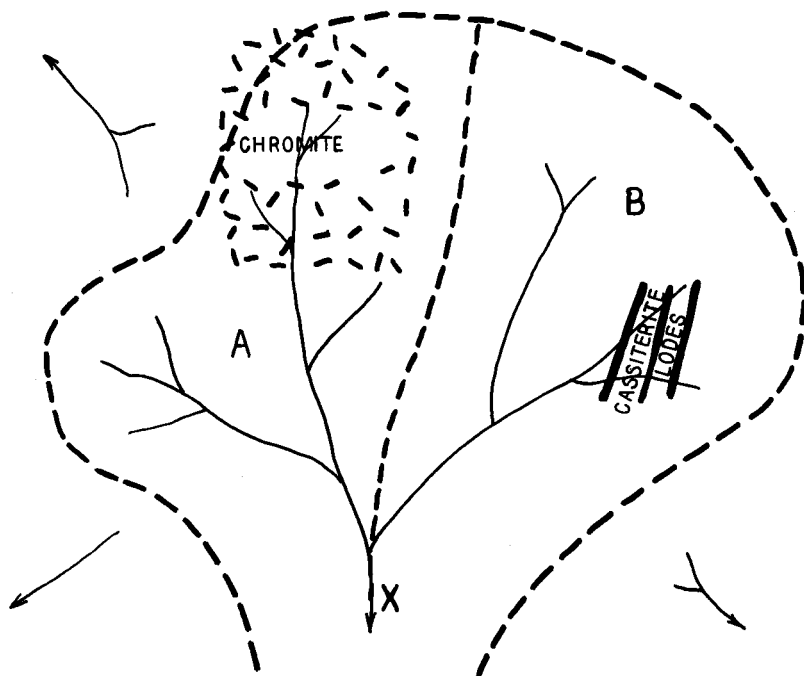


Fig. 15-7 - Two Distributive Provinces. Chromite is limited to province A, Cassiterite to province B.

working his way through a new area, following a river, the minerals which he might pan from a bar may have come from a very large area and will be difficult to trace to their source. It is safe to say, however, that if a sharp increase in the amount of some heavy mineral is noted, that mineral is being eroded from rock not too far distant, and the tributaries in the area should be tested. Gold being malleable and resistant to mechanical and chemical breakdown, travels in fine form farther than the metallic sulfides and oxides. Coarse gold however, travels only a short distance. The first prospectors in the Fortymile drainage were attracted by the finding of fine gold on the bars of the lower river. This is an example of a mining district being discovered by tracing heavy metal in a large drainage area. The smaller the stream, however, the more accurately can a mineralized area be isolated by the finding of heavy minerals in the concentrates.

The less durable minerals, those which break up or are dissolved after traveling only a short distance (mechanical breakdown promotes chemical breakdown), provide a more reliable indication than gold, since they do not travel far, and their presence indicates a nearby source, limiting the search to a smaller area. Wolframite, molybdenite, and to some extent scheelite, are especially indicative of a nearby source.

Fig. 15-7 shows a distributive province A and B, containing two mineralized areas. If concentrates are panned at X, minerals from the whole province A and B may be found. As sampling work progresses into either province A or B, the location of the mineralized areas become more accurately known.

To take full advantage of mineralogical prospecting, it is necessary that the prospector understand thoroughly which minerals are associated together and the association between minerals and rocks. These were discussed in Chapter 7. In a broad way, it is not necessary to find a specific economic mineral in order for the prospector to choose one area and reject another in his search; one mineral may lead to another if they occur together.

Table 15-2, from "Alluvial Prospecting" is reproduced by permission of the publishers. This table does not list many of the economic sulfide and oxide minerals which tend to occur as epigenetic deposits associated with different rocks. Most of these minerals are brittle and unstable and are not carried far. Cinnabar, pyrite, stibnite, arsenopyrite, and galena are examples; cassiterite is an exception. For the association of these minerals with rock types, the reader should refer to Chapter 7.

As a reconnaissance method, mineralogical prospecting should prove valuable. A distributive province should be sampled at intervals along its length, especially around the mouths of tributaries. The presence of a new "suite of minerals" or a sharp increase in the amounts of certain minerals should alert the prospector. Samples are taken below the mouths of tributaries, above the mouths, and up the tributaries. The new tools of geochemical prospecting, especially water sampling, may well be used in conjunction with this type of prospecting. The similarity of mineralogical prospecting to reconnaissance water sampling is evident.

It has been stated that mineralogical prospecting requires no new techniques, but the reader can readily see that it requires a good knowledge of determinative mineralogy. To be able to identify all the minerals in one of the larger sample suites, a person would have to specialize in identification, to the neglect of other equally important phases. It is therefore necessary that the prospector seek help in the identification.

The Alaska Division of Mines and Minerals and the U. S. Geological Survey will identify the minerals in alluvial samples, but if several dozen samples from each of several creeks are to be identified, obviously they cannot do so. Under these circumstances, the prospector can make a careful study of his samples, identifying as many minerals as possible, and send in a sample of each mineral which he cannot identify. Panned concentrates should not be submitted indiscriminantly for analysis; only after diligent work has failed to disclose the identity of a mineral, should it be submitted. After identification, the prospector should determine roughly in what proportions the minerals occur.

In the examination and identification of the minerals in a placer concentrate, the petrographic microscope and the spectroscope are used extensively. Since the techniques of operating these instruments are beyond the scope of this book, simpler, less specialized procedures must be utilized, leaving those minerals which cannot be identified without the microscope to one of the agencies equipped to deal with them. This leaves the prospector to work with those determinative techniques, physical and chemical, already covered under mineralogy.

The identification of a suite of minerals is more difficult than that of one unknown mineral, and besides this, there is the necessity of arriving at an approximation of the relative amounts of each mineral. The following procedure for the field examination of concentrates is taken from "Alluvial Prospecting".

The panned concentrate is examined in the pan for gold, which, if present is amalgamated or, if coarse, left to be picked out when the concentrate is dry. If the presence of cassiterite is suspected, it should be tested for by placing the concentrate in a dish and adding water, metallic zinc, and hydrochloric acid. If cassiterite is present its surface will be colored silver white and its relative proportion can be estimated. The concentrate is then dried, and the cassiterite and gold picked out. A small brush or a softwood stick, frayed and moistened on the end, is used for removing particles. At this time, any large crystals of different minerals such as garnet, pyrite,

THE INDEX SUITES OF ECONOMIC MINERALS

	Economic Mineral	Index Suite	Parent Rocks	Remarks
Group I	Platinum Iridium Palladium (alloy with Pt.)	Titantiferous Mag- netite Chromite [Picotite [Serpentine] [Olivine] Pleonaste [Bronzite]	Peridotite Basic Gabbro and Norite Serpentine	Associated gold is from quartz veins Locally with copper and nickel-bearing ores
Group II	Gold	Group I minerals Pyrite Pyrrhotite Magnetite rich concentrates [Galena] Chalcocopyrite [Blende(Sphalerite)]	Quartz veins in association with various igneous rocks. Conglom- erate. Granite (very rare)	Presence of ultra- basic rock minerals may be suggestive
Group III	Cassiterite Wolframite Columbite Tantalite	Tourmaline Topaz [Fluorite] Lepidolite Monazite [Scheelite] [Molybdenite] Ilmenite and Magnetite Pyrite (when in association with the first four species and near parent rock).	Lodes and ore bodies Pegmatite Granite	Abundant topaz, lepidolite or ordi- nary mica, with or without fluorite, suggestive
Group IV	Diamond	Ilmenite [Serpentine] Magnetite Chromite Picotite Pyrope(garnet) [Olivine] Bronzite [Diopside]	Basic Igneous rocks, e.g. per- idotite. Jasper conglomerate(rare)	
Group V	Corundum Ruby Sapphire	Amethyst Topaz Beryl Chrysoberyl Garnet Spinel Rutile	Crystalline Dol- omite Altered impure limestone Pegmatite	Igneous rocks per- se are seldom re- sponsible for gem stones of corundum
Group VI	Monazite Thorianite	Group V minerals Ilmenite Zircon (hyacinth)	Pegmatite Gneiss Granite	Thorite and thorian- ite are rare; the latter is a certain indicator of mona- zite
Group VII	Beryl(Emerald) Chrysoberyl (Cymophane) (Alexandrite)	Tourmaline Lepidolite Topaz Pyrite Spinel Amethyst	Granite Pegmatite Limestone	Cymophane often occurs with saph- ire A lepidolite-ruby- spinel suite is of- ten suggestive
Group VIII	Garnet Miscellaneous	Minerals of Groups IV & VII	Gneiss Schist	Ubiquitous where metamorphic rocks contribute material
	Olivine (Peridotite)	Minerals of Group I	Basic and ultra- basic igneous rocks	Does not survive long transport

THE INDEX SUITES OF ECONOMIC MINERALS (Continued)

Economic Mineral	Index Suite	Parent Rocks	Remarks
Group VIII Amethyst Miscellaneous (continued)	Smoky and pink quartz Minerals of Group VII	Quartz veins in granite. Amygdaloidal basalt	Agate is suggestive, also quartz-geodes
Topaz	Minerals of Group III Lepidolite Orthoclase Beryl Cassiterite Garnet Amethyst	Greisen Pegmatite Granite	

Note: Minerals in square brackets [] are local and do not survive long distance transport. Wolframite, molybdenite, and scheelite are significant only in alluvial (residual or hillside) associations.

galena, etc., are picked out and separated. If an ultraviolet lamp and a geiger counter are available, the concentrate should be tested for fluorescent minerals and radioactivity. Scheelite in this way is easily detected; if radioactive, the whole sample should be sent to the nearest Division of Mines and Minerals Assay Office or the U. S. Geological Survey.

The dried concentrate is then spread upon a paper, another paper tied over the pales of a weak magnet, and the magnetite removed and segregated. The black minerals are next removed from the residue, and the remainder separated into metallic and non-metallic minerals. Each group is next separated on the basis of color. The minerals of each group are then identified and separated by the standard tests.

References

- Dobrin, Milton B., 1960, Introduction to Geophysical Prospecting, Second Ed.: McGraw-Hill Book Co., New York
- Eve, A. S., and Keys, D. A., 1954, Applied Geophysics, Fourth Ed.: Cambridge University Press, England
- Heiland, C. A., 1946, Geophysical Exploration: Prentice-Hall, Inc., New York
- Jakosky, Jay John, 1950, Exploration Geophysics, Second Ed.: Trija Publishing Co., Los Angeles, California
- Joesting, H. R., 1942, Unpublished Papers written for Territorial Department of Mines (Now Division of Mines and Minerals)
- Mukherjee, N. R., and Anthony, Leo Mark, 1957, Geochemical Prospecting: University of Alaska
- Raeburn, C., and Milner, Henry B., 1927, Alluvial Prospecting: D. Van Nostrand, New York
- U. S. Geological Survey, Geochemical and Mineralogical Methods of Prospecting for Mineral Deposits: U. S. Geological Survey Circular 127
- U. S. Geological Survey, 1960, A Field Instrument for Quantitative Determination of Beryllium by Activation Analysis: U. S. Geological Survey Circular 427
- Wright, 1953, Prospecting with a Counter, RME 4028: A. E. C., Office of Tech. Services, Dept. of Commerce

Chapter 16

AUXILIARY TECHNIQUES

SURVEYING AND MAPPING

Most prospectors do not have a transit at their disposal; besides it is neither practical nor necessary to carry one on prospecting trips. Therefore the surveying methods described here are based on the use of the Brunton compass. If greater accuracy is required, a transit or plane table can be used, following the same procedures as are described for the compass.

Anyone using a Brunton should read carefully the manufacturer's directions. The Brunton is used as a compass to measure horizontal directions, or as a hand level or clinometer to measure vertical distances and angles. When used as a compass, it is held with both hands against the body at waist height, and the observer looks straight down into the mirror, which is inclined so that the object being sighted is seen in the mirror through the slot in the front sight. The image of the slot is made to straddle a line on the mirror, while the operator keeps the Brunton level by watching a bubble, dampens the swing of the needle, and reads the circle to the nearest half degree. If this circle is divided into four quadrants of 90° each, it is said to read bearings and is read as north or south so many degrees east or west. If it is divided into 360° , it is said to read azimuths and is read as so many degrees clockwise from north. The white (north seeking) end of the needle is always read. The Brunton may also be mounted upon a light tripod, and the two sights turned up, through which the object may be sighted. This method is much faster and more accurate.

Where the presence of magnetic bodies is suspected, compass bearings cannot be depended upon. The procedure then is to take a bearing, say, from one end of the base line to the other, then take a bearing on the new point. The difference in bearings or azimuths gives the angle between the lines of sight, which can be plotted without error, since the disturbance of the compass needle will be the same for both bearings at the same point. This method was not followed in surveying some of the early claims at the Klukwan magnetite deposit near Haines, Alaska, and when they were finally surveyed with a transit they were found to be of peculiar shapes.

Used for measuring vertical angles, the Brunton is held on edge, the mirror inclined so that the adjustable level may be seen, and the sight on the end of the slotted post turned up. The observer looks at the object through this sight and the opening in the mirror. If the Brunton is being used as a level, the adjustable bubble is set at zero, and the instrument held so the bubble, as seen in the mirror, is centered. The point at the same level as the Brunton is then noted. When used as a clinometer to read vertical angles, the line of sight is held steady on the point sighted, while the adjustable level is turned by a handle on the bottom of the Brunton. This turning is done with the right hand. When the bubble, as seen in the mirror, is centered, the vertical scale is read, either in degrees or in percent grade. If in degrees, trigonometric tables must be used in conjunction with horizontal distances to compute the vertical distance. If in percent grade, the vertical distance per 100 feet horizontal distance is known immediately. The instrument may be used with the tripod when measuring vertical angles.

Triangulation

HORIZONTAL DISTANCE - If in open country, such as encountered above timber on many creeks, very rapid mapping can be done by triangulation. The method is the same as that used with the plane table. When the plane table is used, each point sighted is plotted on the paper on the board by means of a straight edge parallel to the line of sight. In this way the map is made in the field as surveying progresses. When using the Brunton, it is also possible to make a map in the field, but bearings read with the compass must be plotted with a protractor. If it is not desired to make the map in the field, all bearings may be recorded in a notebook and the information transferred to the map in camp. Some sort of field map should be made as the work progresses, however.

The following simple method of making a map in the field is used by the Alaska Division of Mines and Minerals. Any paper with coordinates fairly close together may be used; it is clamped to a clipboard, aluminum notebook, or sketchboard especially made for mapping. A six inch celluloid rule containing a scale and protractor is kept in an envelope glued in the back of the notebook. (Such rules are available with different scales and several should be kept on hand). The scale is used to lay off the distance of a line, and the protractor to

determine its direction. The center of the protractor, which is the three inch mark on the edge of the rule, is placed on the coordinate line nearest the point through which a line is to be drawn, and the degree reading which gives the desired angle is laid on the same line. The edge then lies in the desired direction. The whole scale is moved up or down the coordinate line, without changing the orientation, until the edge of the scale passes through the point. The line is drawn, and the proper distance marked off from the point. Fig. 16-1 illustrates the use of this method.

In the triangulation method, a fairly level place is chosen, on which can be laid out a base-line several hundred feet long. (The longer the baseline, the more accurate the map). A straight line is laid off, its horizontal distance measured with a tape, and its bearing measured with a Brunton. These figures are recorded, and the line plotted on a piece of map paper. The baseline is the only distance that need be measured with a tape. A point is next chosen and marked with a pole or rock monument, distant from each end of the baseline an amount approximately equal to the baseline. This gives three points of a roughly equilateral triangle. This point, as well as subsequent ones, should be in a prominent location, easily seen. In triangulation, the surveyor always tries to lay out "strong" triangles, meaning that the corners should be formed by two lines intersecting at a fairly blunt angle. Such an intersection of two lines forming more of an acute angle is indefinite and impossible to locate correctly.

Bearings from each end of the baseline to the new point are read and recorded. Lines representing these bearings are plotted on the map through each end of the baseline; their intersection locates the third point. Points in prominent places throughout the area to be mapped are now marked on the ground with stakes to which has been tied a piece of bunting or flagging. These points are located by taking compass bearings from points already established, and in turn they may be used to locate still more. When a point is used to establish a new point, it is said to be occupied. Each time a point is located by triangulation the vertical angle from one point to the other in degrees and percent grade is read and recorded. Down

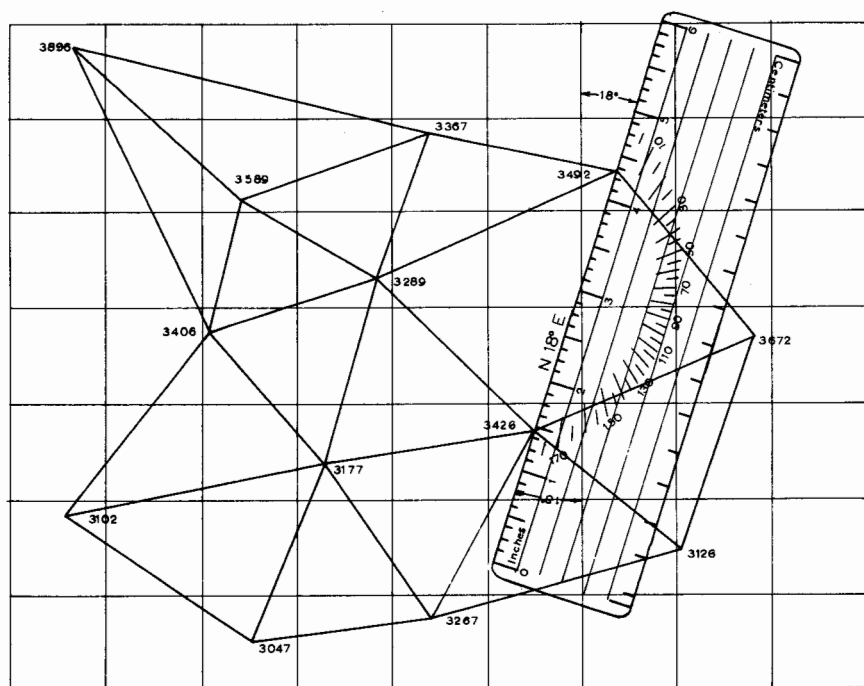


Fig. 16-1 - Method of Plotting Primary Triangulation Net. Bearings are determined with Brunton and plotted as shown with combination scale-protractor, angles being measured from North-South lines of Grid.

slope angles are negative and upslope ones positive.

When the primary triangulation net has been laid out and plotted, the map consists of a series of points, called hubs or stations, throughout the area. The area is mapped from these points. A point is occupied and bearings and vertical angles are measured to peaks, outcrops, points on streams, cabins, shafts, claim corners, etc. which are to go on the map. If the features are close to a hub, their distance may be paced off or taped; if far, their positions are triangulated. Stream or trail meanderings are sketched on the map as the different hubs are occupied. In practice, of course, most of these features are located at the same time that the primary hub is located, to avoid covering an area twice.

VERTICAL DISTANCES - Determining elevations of points or features is a little more difficult, although still fairly simple. The elevation of the initial point (one end of the baseline) is determined by estimating from a map of the region, or it is brought in from a known elevation by barometer. Either method gives inexact results, but this is unimportant because on a sketch map only the elevations relative to one another need be accurate. The absolute elevation is immaterial.

The vertical angle from the first point to the next is measured with the Brunton, and the horizontal distance is scaled from the map. If the angle is in percent grade, the difference in elevation is:

$$(\text{percent grade}) \times (\text{horizontal distance}).$$

If in degrees, the difference is:

$$(\text{horizontal distance}) \times (\text{tangent of angle}).$$

Natural trigonometric tables are located in the back of all engineers' notebooks.

When reading vertical angles it is important to direct the line of sight to a point the same distance off the ground as the Brunton is being held. If a helper is available, he can stand on the point and the Brunton is pointed at his eyes. On long sights, as toward distant peaks, this is unnecessary. Differences of elevation of close objects may be measured by using the Brunton as a hand level. The index pointer is set on zero, the instrument leveled, and the point uphill where the level line of sight intersects the hillside is noted. That point is then occupied, and another point found. This is repeated until the higher point is reached. Of course the difference in elevation will not come out an even number of "eye heights", but a six foot rule can be used to add or subtract from the end reading. The surveyor measures his "eye height", and calculates the difference in elevation which he has measured.

When two men are working together, a level rod is invaluable. This is a pole laid out in feet and tenths, starting from the bottom. The level rod is held on a point, the elevation of which is known, and the man with the Brunton (or hand level) directs a level line of sight toward it. The point at which the line of sight intersects the rod is the backsight reading. The elevation of the eye is now the number of feet represented by the reading above the known point. The rodman next moves to an unknown point, and without leaving his position, the levelman directs a level sight at the rod, the foresight. The reading now tells how much lower the new point is than eye elevation. The elevation of the new point is then:

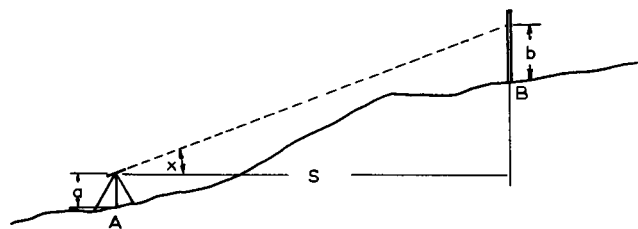
$$\text{Old elevation} = \text{backsight} - \text{foresight}.$$

It may be necessary to take several backsights and foresights between points, with the levelman and rodman "leap frogging"; that is, first the rodman moves ahead, then the levelman. The backsights are then all added to the original elevation, and the foresights all subtracted to determine the elevation of the new point. An ordinary carpenter's level rested on a box or stick can be used to obtain differences in elevation if a hand level or Brunton is not available. The surveyor levels it and sights along its edge at a rule held by his assistant. Fig. 16-2 illustrates leveling techniques.

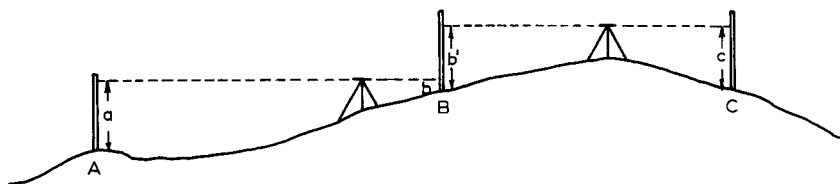
After all points have been plotted and the differences in elevation are computed, the elevation of each point is calculated. Starting with the initial point, the approximate absolute elevation of which is known, the prospector adds or subtracts differences in elevation to find the elevations of the new points.

When all elevations are computed, the elevation of each point is written next to the point on the map, and the contours are sketched in. Contour lines connecting points of equal elevation show at a glance the topography of the area. The choice of contour interval, or vertical distance in feet between contour lines, is determined by the relief of the country and the horizontal scale of the map. It will be remembered that relief is the largest difference in elevation of an area. In mountainous areas, a large contour interval must be used; otherwise contour lines would be too close together on the map. Ten to a hundred feet might be chosen. In more level areas a small interval must be used, or the total relief might lie between two contours, and nothing at all be indicated of the topography - a contour interval of one to ten feet might be suitable.

Contouring is done in the field because more accurate work is done when the surface is actually visible. Contours are brought close to or kept far from a point depending on how nearly



$$\text{Elev. pt. B} = \text{Elev. pt. A} + a + S \tan x - b$$



$$\text{Elev. pt C} = \text{Elev. pt A} + a - b + b' - c$$

Fig. 16-2 - Levelling Techniques

the same elevation are the point and the contour. For instance, with a ten foot contour interval, a point with elevation 2218 feet would be much closer to the 2220 foot contour line than to the 2210 foot line.

EXAMPLE OF MAPPING BY TRIANGULATION - An actual example, in which about four miles of creek was mapped, illustrates triangulation. The map of the creek, of course, was to be long and narrow. Although the creek was above timber line, thick willows in the creek bed obscured visibility. Four lines of holes had been drilled, and each hole was marked by a post. The benches on each side of the creek were open, affording good visibility.

Stakes were set well up on each bench in line with each drill line for triangulation points. As these lines were about 2000 feet apart, other stakes were set on the benches between them and up and down the creek from the drilled area. When finished, two rows of flagged stakes, one on either bench, extended along the creek. The distance between two of the stakes was taped for a baseline, and all the other points were located by triangulation. The position of all visible objects, such as buildings and features on the benches were triangulated. To locate the drill holes in the brush and the course of the stream, however, it was necessary to use actual measurements. Lines were brushed (just enough brush was cut so that the surveyors could get through) between pairs of stakes on opposite benches. Four of these lines were along drill lines. The features along each line were located as follows. A 100 foot steel tape was stretched from one stake along the brushed line, and the distance to particular objects was noted. The tape was then moved up and the objects in the next 100 feet were noted and recorded. These objects included drill holes, shafts, old cuts, and the stream. Objects not exactly on the line were described as so many feet upstream or downstream from a particular distance along the tape. The elevations of the points along the cross sections, as such lines are called, were determined by hand leveling, using a level rod and Brunton. When the points were all plotted, it was only necessary to sketch in the creek between cross sections and to draw the contours.

Traversing

In wooded or brushy country it may not be possible to triangulate the points. The hubs are

set throughout the area and lines are brushed between them, taking advantage of any open spaces to minimize brushing. Traverses are then run to connect the hubs. A traverse is the path followed in going between the first and last hubs. The straight line between any two adjacent hubs is a course and is described by a distance and a compass bearing. The distances may be paced, but in rough country it is better to measure them with a tape. (A cloth tape giving fairly good accuracy weighs very little). Early surveyors used a chain of known length, and even today when a distance is measured with a tape the distance is said to be "chained". Accurate chaining requires constant attention. The chain or tape is held level and a standard pull exerted. On sloping ground, one end of the chain is on the ground, and one end is held in the air. For accurate work, a plumb bob is used to determine the point under the high end of the chain. For much work, however, it is sufficiently accurate if the chainman who is holding his end of the tape off the ground (the down-slope man) drops a pebble to mark the point.

After the primary traverse has been run and plotted, the objects to be mapped are located by bearing and distance from a hub. Side traverses may be run along tributary creeks or trails. Elevations of the hubs are determined as in triangulation; only in this case, it is not necessary to scale the horizontal distance from the map as it has been measured directly.

In this very brief discussion two methods of surveying have been described, triangulation and traversing. These methods are basic and can be used with any desired degree of precision by using more precise instruments. The methods which have been described here give an accuracy of about one in 100; that is, a point which is supposed to be one hundred feet from another may be 99 feet or 101 feet. How much accuracy to strive for depends on the use to which the map is to be put.

The surveyor must be ready to take advantage of conditions as they arise, such as being able to triangulate part of an area being traversed. Most surveys combine a number of procedures. It may even be possible that objects close to a hub or triangulation point can be plotted on the map merely by estimation of direction and distance.

Maps

The map is drawn at some convenient scale, which depends on the use. A map to be used for laying out drill holes should be drawn to a scale of from 100 to 200 feet to the inch, or even larger. (Large scale means less feet to an inch). A map to be used for plotting geology of a general area might have a scale of from 1000 feet up to one mile to the inch. An engineer's scale, laid out in multiples of ten feet to the inch, is always used in laying out maps. Scales of twenty, forty, or one hundred feet to the inch are called simply twenty, forty, or hundred scale. (This point is important. Before a scale is purchased, it should be examined to make sure it is not an architect's scale, which is divided into feet and twelfths because architectural measurements are made in feet and inches). The scale used should be recorded on the map.

Surface Geologic Mapping

The map resulting from the surveying described thus far is called a topographic map. If it is desired to put geological features on the map, the same procedures are followed, plus a few others. The topographic map in this case will be the base map for the geology of the area.

During the topographic surveying, ample opportunity is afforded to look over the country in a general way. Any differences in rock types, intrusions, or other geological features are watched for and noted. When the geological mapping starts, contacts between rock types or types of overburden are plotted, using the topographic features already mapped as guides. The outcrops of veins, dikes, beds, or other tabular bodies are plotted, with their strike and dip noted on the map. The symbol for strike and dip is $\frac{\text{---}}{\text{---}}$. The long line is plotted in the direction of the strike and the arrow points in the direction of down dip. The angle of dip is written beside the arrow. Strikes are taken by finding a level line on a bed or vein and taking its bearing with the Brunton. The dip is taken at right angles to the strike by opening the Brunton and laying it on a good exposed face of a bed. If good faces are not available, the Brunton is held at arm's length and its edge lined up with the dip of the structure. The bubble is leveled and the vertical angle read. Dip angles are read from the horizontal down. As each dip and strike or other geologic feature is plotted on the map, its position is given a number, which is also written on the map. The number, with the dip and strike, and a short description of the rock and structure are then entered in a notebook. In this way the information in each observation is plotted on the map and described in the notebook. If a rock sample is taken at a point, it is labelled with the same number as the point put on the map. Faults and shear zones may be favorable places to prospect, but they are difficult to locate on the surface. The importance of features such as notches in saddles or bands of willows, which might betray the presence of faults, is discussed in Chapter 10, and these features should be mapped. If prospecting subsequently proves them to be faults or shear zones, they may be labelled as such on the map, and an attempt made to determine their strikes and dips. Veins are plotted in red, faults in blue. An aerial photograph makes perhaps the best base map, because outcrops, streams, lineations etc. can be seen direct-

ly. Geology can be plotted right on the photo with India ink or on a transparent overlay (frost-ed acetate is best). Samples may be located by punching a hole through the photo with a pin and numbering it on the back.

READING GEOLOGIC MAPS AND AERIAL PHOTOGRAPHS

Geologic Maps

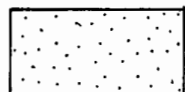
The geology of an area is best represented as a geologic map. Symbols, more or less standardized, are used for structural features and colors or designs for different rocks. Geologic sections, showing the underground geology, are cross sections along some line on the map. Geologic columns show the sequence of rocks in an area, oldest on the bottom, youngest on top.

On the map, the areas occupied by each rock type are outlined and colored or marked with a distinctive design. These areas are identified by letters, the first of which represents the period to which the rock belongs, the others the initial letters of the formation name, i.e., Precambrian Birch Creek schist is symbolized P-Bc (the "C" in "Cambrian" is written with a bar to avoid confusion with "Carboniferous").

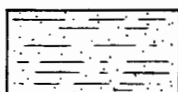
Contacts between formations are drawn as solid lines if known, or as dotted lines if inferred. Faults are heavy solid or dotted lines (also for known or inferred). The axes of anticlines are solid lines with arrows pointing outward, and the axes of synclines are lines with arrows pointing toward them. Where dips and strikes are known, they are plotted symbolically.

On one side of the map a legend shows all symbols used; this legend actually is a geologic column, because the oldest rocks are at the bottom, the youngest at the top.

Fig. 16-3 shows some symbols in common use. Fig. 16-4 shows a typical geologic map and section.



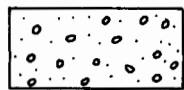
Sand or sandstone



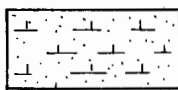
Shaly sandstone



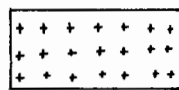
Igneous rock



Gravel or conglomerate



Limey sandstone



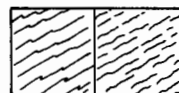
Igneous rock



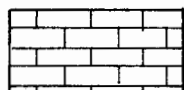
Shale



Limey shale



Schist



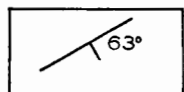
Limestone



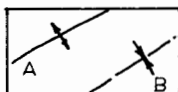
Dolomite



Lava flows



Strike & dip

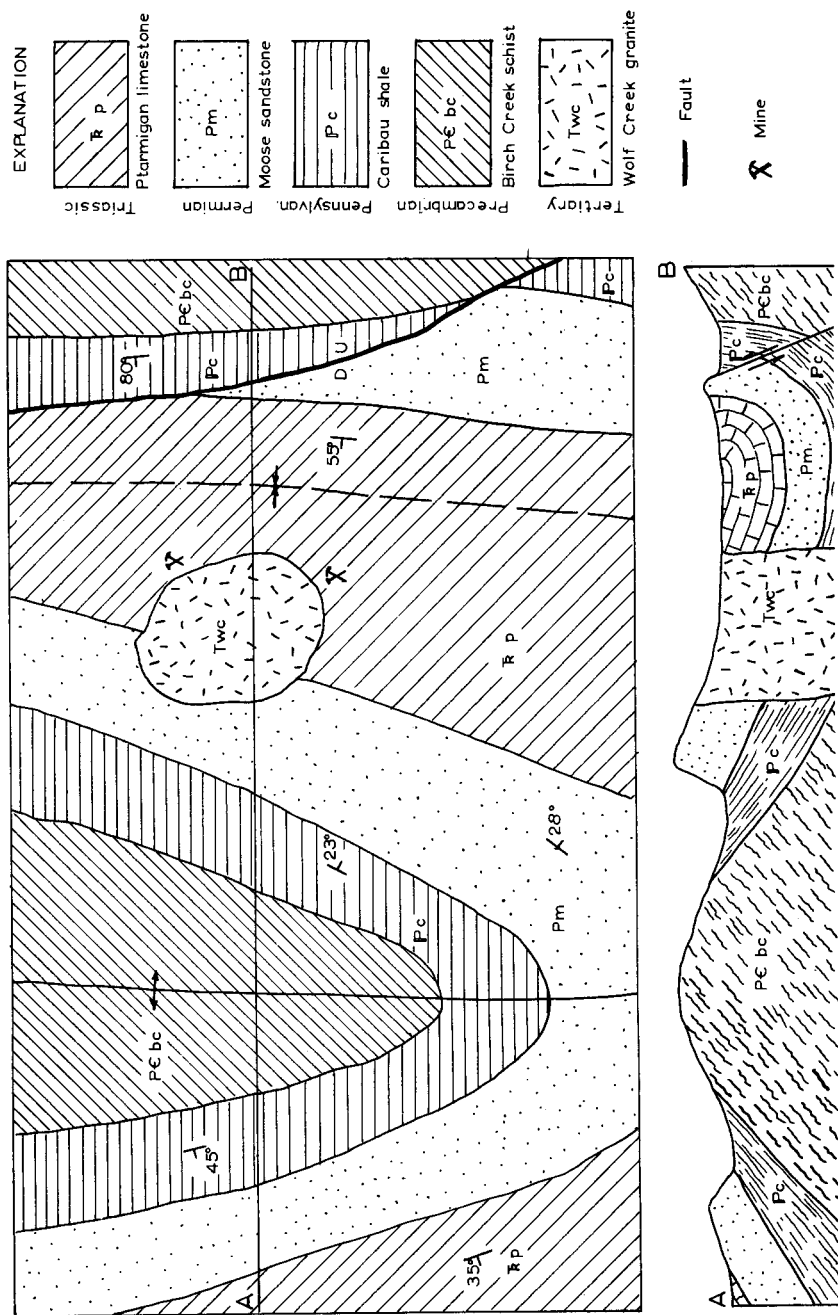


Axes: A, anticline
B, Syncline



Bedrock

Fig. 16-3 - Some of the Symbols Used on Geologic Maps and Cross Sections.



Aerial Photographs

Aerial photographs, when viewed singly, provide the prospector with a useful means of examining the structures and topographic features of an area. To derive full benefit from aerial photographs, however, they should be viewed in stereo-pair; that is, two overlapping photos of the same area are viewed through a stereoscope (two lenses on a stand, with or without auxiliary prisms and mirrors). The simplest and most satisfactory stereoscope for the prospector is a pocket stereoscope, which, when folded, fits into a shirt pocket and can be carried into the field. The pocket stereoscope can be purchased at most engineering and drafting supply houses.

Stereo-pair photographs provide a uniquely useful means of examining an area. When properly adjusted and viewed, the surface is seen in three dimensions, with the vertical relief exaggerated. This exaggeration makes readily apparent features which are invisible on the ground, or even from the air. Whenever stereo-pair photographs of an area to be prospected can be obtained, they should be used. Aerial photographs are taken from different heights and hence have different scales. Common scales are about 1.2 miles per inch and 3.2 miles per inch.

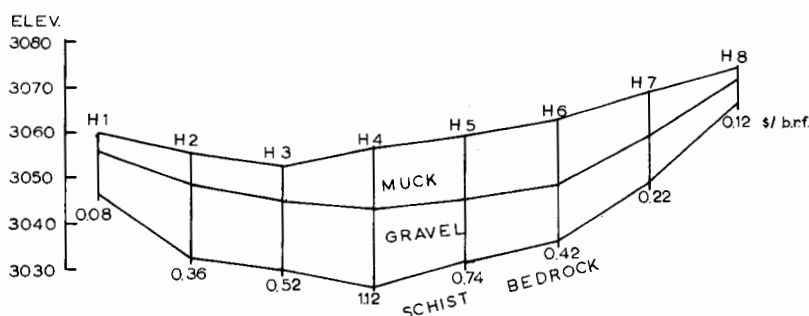
The photographs are placed side by side on a flat surface, oriented in the same way, and separated by about the same distance as separates the lenses of the stereoscope. The stereoscope is placed over the photographs so that each lens is above a like point on each photograph. The photographs are then viewed through the lenses and manipulated until three dimensional vision is obtained.

The photos should be examined beforehand and all geological features which can be identified should be noted (this is called photogeology). They should further be observed as the examination of the country progresses; features seen on the ground should be examined on the photos, and features seen on the photos are examined on the ground. With a little practice, stereo vision can be achieved by looking at a stereo-pair without a stereoscope. There is no magnification, however, and it is not a particularly satisfactory method.

If photos are carried into the field, they must be protected. A simple way to do this is to cut two pieces of cardboard slightly larger than the photos and tape them together on three sides. The photos are kept between the cardboards and slipped out as needed. Sources of aerial photographs are listed in Appendix I.

Drill Hole Profiles

The placer prospector always plots on paper the cross sections of his creek as shown by drill holes or shafts. This is done by determining the elevation of each hole in the crosscut and drawing the profile of the surface along the line. The drill holes or shafts are located on the profile, and the depths to bedrock are laid off vertically downward from each hole. Depths to muck and gravel are also plotted, and some sort of symbol is placed at bedrock to denote the amount of gold recovered. Several of these profiles lined up sometimes provide an idea of where to sink further holes. Profiles may be plotted on the map or on separate sheets. Fig. 16-5 shows a drill hole profile.



DRILL HOLE PROFILE
LINE 4, WILLOW CREEK

Horizontal scale: 1" = 50'
Vertical scale: 1" = 20'

Fig. 16-5 - Drill Hole Profile

Underground Mapping

Mapping underground differs somewhat from surface mapping, but the principles are the same. A base map of the workings is made by compass and chain traverse. A miner's lamp is used as a target in sighting from one station to the next. Differences in elevation between points on the same level are determined as in surface surveying.

Surveying from one level to the next presents the greatest divergence from surface mapping procedure. Surveying down an inclined shaft is accomplished by chaining the slope distance, measuring the vertical angle, and taking the bearing. The horizontal distance between points at top and bottom is:

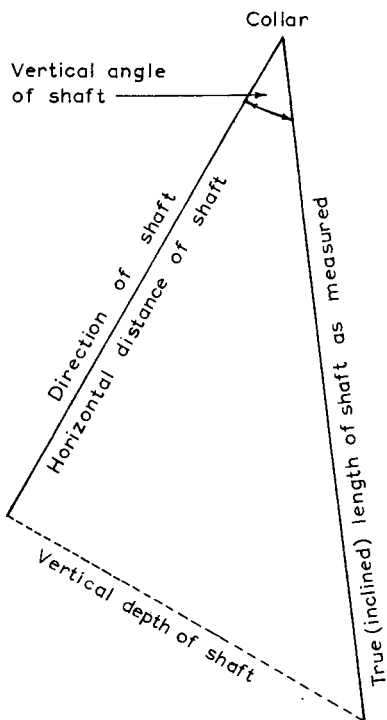
$$(\text{slope distance}) \times (\cosine \text{ of vertical angle}).$$

The vertical distance is:

$$(\text{slope distance}) \times (\text{sine of vertical angle}).$$

Bearings are transferred down a vertical shaft by suspending two wires, each with a heavy weight attached to the bottom, on opposite sides or corners of the shaft. The bearing between the wires at the top and at the bottom is the same. The vertical distance is chained direct.

For steep angles, such as are found in inclined shafts or winzes, the horizontal and vertical components may also be found graphically as follows: the bearing of the shaft or winze is plotted on the map, extending from the initial point in the direction of the shaft. From the plotted initial point, the vertical angle is laid off between the plotted bearing line and a new line. The two lines then intersect at the initial point, with an angle equal to the vertical angle between them. The slope distance is laid off along the new line and a line dropped from the end point to the bearing line, perpendicular to the bearing line. The distance from the initial point to the point where the perpendicular strikes the bearing line is the horizontal distance. The length of the perpendicular line is the vertical distance. This graphical method of finding vertical and horizontal distances from slope distances may also be applied to surface surveying. Fig. 16-6 illustrates the graphical method.



After the traverse tying together primary points is completed, the openings themselves are measured. A chain is laid on the floor between points or stations, and the distance right and left from the tape to the walls and the height of the back are measured with a six foot rule. These readings are taken each five or ten feet and recorded in a note book.

Although on the surface the map is sometimes not drawn in the field, underground the sketch map is always made while the survey is in progress and the notes are being gathered. When the outline of the workings is complete, the geology is sketched in. Schistosity, bedding, veins, faults, changes in country rock, alteration zones, intrusives, etc., are put on the map. Although practices differ, most geologists map structures at "waist height". This term means that the plane of a vein, fault, or other structure must be projected to waist height. If a vein is exposed in the back of a drift and is dipping toward the observer's left, it may be outside the drift when it reaches waist height. Consequently it is plotted on the map to the left of the drift. If the vein is exposed on one side of the drift and strikes waist height about in the middle of the drift, it is plotted there. In tracing veins beyond faults, such underground geological maps are invaluable.

Fig. 16-6 - Graphical Method of Determining Difference in Elevation and True Horizontal Distance when Inclined and Vertical Angle are known.

Conclusion

The foregoing brief description gives the basic practices involved in mapping with Brunton and chain. It is improbable that anyone absolutely unfamiliar with surveying would be enabled to map his area simply by reading this account. However, by referring to more detailed accounts whenever a problem arises and by following the general guide given here, work of an acceptable accuracy can be done by the prospector.

DRILLING ROCK FOR BLASTING

Hand Drilling

Rock may be drilled by hand or by machine, but in remote areas, machine drilling usually is not justified during prospecting or in the early stages of exploration. Hand drilling, if done by one man, is called single jacking; if by two, double jacking. The single handed hammer, weighing from three to four and a half pounds, is called a single jack; it may be provided with a thong which is slipped around the driller's wrist. The double handed hammer, weighing from eight to sixteen pounds, is called a double jack. In single jacking, the driller holds a chisel-bitted hand drill in one hand and strikes it with the hammer; in double jacking, one man holds the drill while the other man strikes with the hammer. During either operation, the drill is rotated between each blow so that a new position is struck. This rotation insures a round hole. When rock chips and dust accumulate to where they form a buffer between the steel and the rock being drilled, they are removed by a scoop made especially for the purpose or, if a down hole is being drilled, water is added to keep the cuttings in suspension.

Single jacking is practicable to depths of two to three feet; double jacking to six or eight feet. For the deeper holes, the steel is changed every two feet or oftener if the bit becomes dull. The new steel must have a gauge one-eighth inch less than that of the steel preceding it, because, during drilling, the bit size is reduced by abrasion, and the bottom of the hole has a smaller diameter than the top. The smaller the diameter of the hole being drilled the faster the speed. Although no exact rule can be given, doubling the diameter will at least double the time necessary to drill a given depth. In single jacking, the one handed blows do not provide enough power to drill with large diameter steel. To make satisfactory progress, steel having bit gauges of $3/4"$ or $7/8"$ is usually used. To load these holes, the ordinary dynamite cartridge of $1 1/8"$ or $1 1/4"$ diameter must be opened up and the explosive molded into the hole without the wrapper. For deep holes, either single-jacked or double-jacked, where the use of steel with progressively smaller bits is necessary to finish the hole, the starting bit must be larger, for instance $1"$, $1 1/8"$ or $1 1/4"$.

The direction of the hole affects the speed of drilling. Horizontal holes take about twice as long as down holes; upward holes take even more time. The hardness of the rock also affects the speed; limestone may be drilled almost twice as fast as granite.

All drills used for hand work have until recently been made of carbon steel that must be sharpened periodically. Such drills range in size from $3/4"$ to $1 1/2"$, depending on the depth of the hole, amount of powder to be used, and other factors. Detachable bits which can be thrown away when dull or drill steel with tungsten carbide inserts in the bits have been in use for many years in machine drilling processes. Recently, Canadian firms have begun making sets of handsteel with tungsten carbide chisel-bit inserts which sell for about \$14.00 each. The use of such drills eliminates the prospector's need for having a blacksmithing outfit for sharpening his steel.

Power Drilling

Power drills usually are driven by compressed air; for underground work this power source is the only one practicable. For work on the surface, however, the recently developed gasoline powered drills are satisfactory. Modern power driven drills are almost all of the hammer drill type. In this type of drill, the bit remains against the rock at the bottom of the hole, rebounding slightly with each blow supplied by a reciprocating hammer striking the other end of the steel. In an earlier type, the piston drill, the drill steel was fastened to the piston and moved back and forth with it.

Hammer drills are classified as hand held, drifters, and stopers. Hand held drills are usually built for drilling down, although the lighter models may be used for horizontal holes. Sinkers weighing up to 135 pounds are hand held drills used in shaft sinking. Drifters are used for driving drifts, and are the heaviest of the hammer drills, weighing up to more than 200 pounds. They must be mounted upon a column or bar. Stopers are designed for working in narrow spaces and for drilling upward. No mounting bar nor column is required as the back of the drill has a telescoping tube which rests upon the ground or a timber. Compressed air forces the tube out and keeps the drill against the work. Stopers are lighter than drifters, weighing from 70 to about 100 pounds.

Most drills are provided with automatic rotation devices, but a few must be rotated by hand. All drifters and stoppers are provided with some means of feeding the drill to the work. Some drifters are provided with a pneumatic feed similar to that used on the stopper; others have automatic or hand screw feeds.

Several different methods of mounting drills are used: Column mountings are posts or rods which may be lengthened by a screw jack, a hydraulic jack, or a pneumatic device. By lengthening, the column may be jammed between the back and the floor of a drift or between the walls. Wooden blocks and wedges are inserted between the ends of the column and the rock. Sometimes a heavy tripod is used as a mounting. Quarry bars are horizontal bars supported by four legs. A jock leg, or stinger, is a single telescoping staff lengthened pneumatically, upon which a drill is mounted. This converts a hand held drill into a light drifter or stopper. Although the drill must be handled somewhat as a hand drill, the jackleg supports its weight and in upward drilling provides the feed.

Power driven rock drills must be provided with a means of clearing cuttings from the hole by introducing either water or air, usually both, through the hollow shank of the drill steel. The drill is classified as dry if air is used or wet if water is used. Dry drilling underground is dangerous because the dust created causes silicosis, a disease of the lungs. For this reason, Alaskan law states that water must be introduced into the hole to lay dust during underground drilling.

Air is brought from a compressor to the receiver tank, which provides storage capacity so that an ample uniform supply of air is available; and from the receiver the air goes to the drill. Water should be supplied at less pressure than is the air, to prevent the water from being forced into the drill cylinder, carrying away the lubricant. Pressure on the water is usually obtained by diverting some air to a water tank and running a water line from the tank to the drill.

The purchase and transportation of compressor, pipe, receiver tank, drill, hose, water tank, and other equipment represents an investment usually unjustified until extensive underground work is to be undertaken. The recent development of successful gasoline driven hammer drills has made it possible to do power drilling on or near the surface without such a large initial investment. At present there are three such drills on the market: one American, one Canadian, and one Swedish. These drills weigh 80 to 90 pounds. Some types introduce air into the hole to blow away the cuttings; one exhausts through the tube alongside the drill steel to accomplish the same thing. The drills using air to keep the hole clean have exhaust tubes so the exhaust fumes may be conducted some distance away, an arrangement which allows work to be carried a short distance underground. These drills cost about \$800 in Alaska and consume approximately one half gallon of gasoline and one fourth pint of oil per hour. The model using engine exhaust for clearing the hole can be used to drill about three feet deep; those using compressed air will drill about eight feet.

After the holes for any particular blast have been drilled, they are cleaned out, using a scoop, or, if available, compressed air. They are then tested with a stick to make sure no obstruction is present, and if all is ready, they are loaded with dynamite. If some delay is to be encountered, each hole should be plugged with a piece of wood to keep dirt from falling in.

The chief difficulty encountered in rock drilling is sticking or fitchering bits. Peele notes several causes of sticking bits: poor alignment of steel in hole, bent steel, improper type or poorly sharpened bit, too much or too little feed water, worn or broken shanks, seamy rock, pebbles or spalls falling and jamming alongside the bit, mud collar building up behind the bit, hard nodules in rock causing poor alignment of hole, and bending of the drill shank. Most stuck bits are caused by sloughing of the hole; this sticking is most troublesome in soft rock, such as disintegrated schist. Sometimes when soft rock, such as occurs in a fault, is encountered, a hand auger must be used.

None of these problems is peculiar to Alaska. One, however, is encountered in the north that is little known elsewhere: that of drilling frozen bedrock. If a pneumatic drill is being used, with water being supplied through the shank, some of the difficulty with sticking bits in soft ground may be eliminated by the use of "side hole" bits (those in which the water comes out the side of the bit, rather than the end). Another expedient is to use chisel bits instead of cross bits. The chisel bit has more room for cuttings to flow by the bit than do the other types.

Augers

For drilling coal, soft rock, or unconsolidated material, an entirely different type of drill using auger bits is used. Auger drills, like hammer drills, come in a large number of styles and sizes. The simple hand auger which drills a hole about one inch in diameter weighs but a few pounds, whereas a stationary gasoline driven auger weighs over a ton. There are also portable power augers, driven by air or electricity, which are similar to coal augers. Earth augers for drilling unconsolidated or decomposed material are also similar to coal augers. Such augers, however, may be driven by gasoline engines since they are used on the surface. One

such auger, designed to be held by two men, weighs about ninety pounds.

USE OF EXPLOSIVES

Explosives provide a useful, and for some purposes, an irreplaceable tool for the prospector. Because of the danger involved in the use of explosives, it is absolutely necessary that the prospector, before handling them, be thoroughly familiar with proper techniques and safety rules. Modern explosives, if properly handled, are as safe as any other tool of comparable power; if improperly handled, sooner or later they cause destruction of property or life.

Explosives are divided into many products but the first and largest subdivision is into deflagrating or low explosives and detonating or high explosives.

Low explosives are black powders, the slowest acting of all explosives. They are not used now in mining or prospecting, although they are used in certain dimension stone quarrying operations. They have an action which tends to break materials into large firm chunks. Several grades are available for different work. Black powders actually burn; hence are detonated by flame and cannot be used where there is danger of starting a fire. They are free pouring and can be used to fill irregular cavities. They soak up water easily and, consequently, cannot be used in wet areas. They create more smoke and poisonous gases (known as fumes) than do most dynamites.

Black powders consist of carbon (charcoal), sodium or potassium nitrate, and sulfur. When finely powdered, this mixture burns with explosive suddenness, converting most of its bulk into gases, which, occupying a very much greater volume than the original ingredients, exert a pressure upon their surroundings. Methods of igniting black powder are by imbedding an ordinary safety fuse in the powder or by an electric squib, which is an aluminum shell containing black powder ignited electrically. If the prospector should ever have a special blasting job which he believes might be best met by the use of black powder, he should first consult a specialist in explosives. Because high explosives are far superior to black powder for the vast majority of the blasting work encountered in prospecting, the rest of this section is concerned with high explosives, or dynamite.

As dynamite decomposes to gaseous products almost instantaneously, it has a more violent shattering effect than does black powder. Almost all dynamite is packed in sticks or cartridges of explosive wrapped in waxed paper. A small percentage of free flowing dynamite is packed in bags, but it is doubtful if a prospector would have occasion to use such dynamite. Small cartridges are those less than two inches in diameter, and large ones are those greater than two inches in diameter. The prospector is most likely to use cartridges eight inches long and 7/8" to 1 1/4" in diameter. When dynamite cartridges must fill a hole of diameter greater than themselves, the paper is slit so that the cartridge can expand as it is pushed in. Some dynamite comes wrapped in a perforated wrapper which will burst and allow expansion when tamped.

Types Of High Explosives

Dynamites come in many types and grades, each possessing particular characteristics. There are 1. Straight Dynamite, 2. Ammonia Dynamite, 3. Straight Gelatin, 4. Ammonia Gelatin, 5. Blasting Gelatin, 6. Granular Dynamite, 7. Special Coal Mining "Permissible" Dynamite, 8. Nan-nitroglycerin Explosives, 9. Liquid Oxygen Explosives.

Straight dynamite is nitroglycerin sodium nitrate and an anticid held in a binder of wood meal, which makes a pulpy, crumbly, easily molded explosive. The strength of straight dynamite is expressed by the percentage of nitroglycerin contained, usually 15 to 60. Straight dynamites are fast acting and the most sensitive to shock of all dynamites. They are ill-suited to poorly ventilated places because of the fumes they give off, are only moderately waterproof, and are quite inflammable.

Ammonia dynamites have ammonium nitrate as part of the explosive ingredient. They are slower and less sensitive than straight dynamites, more fireproof, but less waterproof.

Gelatin dynamite is a jelly made by dissolving nitrocotton in nitroglycerin. Straight gelatin dynamite has good plasticity, is waterproof, and gives off relatively few fumes. Gelatins are made up to 90 percent strength. (Strength is always expressed in terms of a comparable straight dynamite).

Ammonia gelatin is similar to straight gelatin but is slightly less waterproof.

Blasting gelatin is straight nitroglycerin gelatin and is the most powerful and waterproof of all dynamites. Its consistency is somewhat like soft rubber, making it hard to mold. It is a poor fume dynamite and dangerously sensitive to shock when frozen.

Granular dynamite is free pouring and the slowest acting of all dynamites. It is designed to take the place of black powder.

Permissible dynamites are those passed by the U. S. Bureau of Mines as being safe for use in coal mines or other places where coal gas (methane) may be encountered. Their chief characteristic is that they produce a low temperature flame of very short duration

which will not ignite coal gas or coal dust.

Non-nitroglycerin explosives have made great strides in recent years, although it is doubtful if they will find use in prospecting. Explosives manufacturers call these "blasting agents." The explosive is packed in tin cans which are introduced, without being opened, into the hole to be blasted. Thus they are perfectly waterproof, do not produce headache through contact with the skin, and are cheap and non-freezing. Their prime qualification, however, is that they are so insensitive to shock or heat that they cannot be detonated by blasting caps, open flame, rifle bullets, or even primacord. Misfires can be drilled out with safety if the drill is kept cool with water. Detonation is accomplished with dynamite or special primers which are set off with caps.

Liquid oxygen explosives (LOX) have been used in coal stripping in the United States but have no application to prospecting.

Properties Of High Explosives

The properties of high explosives are strength, density, velocity, water resistance, freezing resistance, inflammability, and fumes.

The strength of any explosive, as noted earlier, is determined by comparing it with straight dynamite. If it has the same strength as forty per cent straight dynamite, it is said to be of forty per cent strength. Density is expressed as the number of one and one quarter by eight inch sticks per fifty pound box; density varies from about 83 to 205 cartridge per case. The reason for varying density is so that differences in concentration of the blast may be achieved. Velocity refers to the speed in feet per second with which the shock wave travels through the explosive; dynamites range from 4000 to 23000 feet per second in velocity. As velocity increases so does the shattering effect.

The terms water resistance and freezing resistance are self-explanatory. If water is encountered and the explosive is to be in contact with it only a short time, only medium water resistance is necessary, but if the explosive will be exposed to water for a long time, high water resistance is required and gelatin dynamite should be used. Most modern explosives will not freeze until the temperature drops to -65°F., although they may become very hard. A common pin may be used to tell the difference; it will not penetrate frozen dynamite but can be pushed into material that is merely very hard. The pin should be used for the full length of the stick. Frozen dynamite must be carefully thawed by placing it in an area of normal temperature. It must not be placed near open flames or in any device in which the temperature can ever exceed 150°F.

Inflammability refers to the ease with which explosives ignite. Flames from safety fuses have been known to ignite the charge so that relatively low inflammability is desirable. Fumes are the poisonous components of the gaseous products of explosion. Low fume dynamite can be used in places having poorer ventilation than high fume dynamite. Fumes are less extensive when dynamite is exploded in a tightly confined space; hence adequate tamping and stemming are essential to a safe low fume blast. Fumes can and do cause death. At the least, they are responsible for headaches and nausea if the blasting site is approached too soon after an explosion. Any explosive containing nitroglycerin may cause headache if it comes in contact with the skin; it should be washed off immediately.

Detonating Dynamite

Dynamite is detonated in a number of ways, the most common of which is by safety fuse and cap. Safety fuse consists of a train of black powder wrapped in more or less waterproof material. Most safety fuse burns at a uniform rate of around 40 seconds to the foot, although the speed of some types is approximately 30 seconds to the foot. Blasting caps are copper or aluminum shells containing a very sensitive explosive. One end of the shell is hollow so that it can be slipped over the safety fuse and crimped. The heat from the flame at the end of the fuse causes the cap to detonate, which in turn explodes the dynamite in which it is buried.

Caps come in sizes No. six and No. eight, although the latter are practically obsolete because the No. six is strong enough to detonate all commercial explosives now on the market. Caps are the most sensitive to shock and heat of any explosives which the prospector will encounter and must be treated with great caution. They are never carried loose but kept in their box and padded with cotton to keep them from rattling. They must never be tampered with or touched with metal, and if they become wet or show signs of corrosion, they must be destroyed.

Electric blasting caps are detonated by an electric current. They are used as ordinary caps, except that no fuse is necessary. Some are fitted with shunts which keep them short circuited until they are to be used. Electric caps are usually detonated by small, hand operated generators called "blasting machines."

Primacord is high explosive in a cord-like sheath. It has a velocity of nearly four miles per second; consequently short lengths can be considered to detonate instantaneously. Although

it is a high explosive and should be treated with caution, it is very insensitive to shock. It is detonated by a blasting cap which is taped to it. It is used to connect charges in different holes so that they may be detonated simultaneously; branch lines are simply connected by tying.

Storage And Handling Of Explosives

The prospector should see that his dynamite is stored with three thoughts in mind: to protect the public, to protect himself, and to protect the explosive. Any shelter which keeps the dynamite off the ground, keeps rain and animals out, and is cool and well ventilated is satisfactory for protecting the dynamite. The public is best protected by providing the shelter with conspicuous signs and, if possible, making the shelter bullet proof. If the shelter is small, say designed for a few cases, this bullet-proofing can be done by piling rocks or dirt around it. The shelter should be locked to bar children and irresponsible persons, and inflammable brush and grass should be cleared from around it. The prospector is protected by having plenty of distance and an intervening rise of hillock between his dynamite cache (called a magazine) and his residence. This distance, for 50 pounds of dynamite, should be about 75 feet; for 200 pounds, about 200 feet; for 1000, over 500 feet. If natural barriers do not occur between the magazine and the residence, this distance should be doubled; the magazine, however, should be close enough so that it may be inspected at frequent intervals. Stocks should not be allowed to get old; the oldest should be used first. Open flames should not be used for light nor should smoking be allowed in the dynamite cache. Caps are never stored with high explosives; caps and fuse may be stored in an ordinary cache with other nonmetallic supplies where they will be dry and not subject to shock. Caps must be kept out of reach of children. Fuse should not be hung over a nail or hook, as a slight kinking, especially in cold weather, might cause a break and a subsequent side spit or misfire.

Dynamite, fuse, or caps which have been wet should be destroyed. Dynamite several years old, especially if it has been exposed to high temperatures, as direct sun rays, may have nitroglycerin separated out and accumulated on the wrapper. Such dynamite is very sensitive to shock, must be handled carefully, and destroyed as soon as possible. If nitroglycerine soaks into the floor of the magazine, the manufacturer of the dynamite should be contacted; he will recommend a washing compound. Broken cartridges must be destroyed and any spilled contents of such a cartridge must be swept up and destroyed.

The best way to destroy dynamite is to burn it. The cartridges should be slit and spread over combustible material which is fired by lighting a train of straw or other combustible material leading up to the main fire so that the prospector may withdraw to a safe place in case of explosion. No more dynamite should be burned at one time than will explode safely should the dynamite detonate instead of burn. In isolated areas the dynamite may be destroyed by exploding, although sometimes trouble is experienced in detonating old deteriorated dynamite.

Caps which have been wet must be destroyed because the shells may be corroded, making their behavior unpredictable. Caps, not more than one hundred at a time, are buried about a foot deep, along with a dynamite primer, and then detonated. Primacord is destroyed by burning. Black powder and fire resistant blasting agents may be poured into streams.

No explosives should ever be abandoned, and in burning them, the prospector must always keep in mind the fact that they may explode.

Transportation Of Explosives

Likewise, the transportation of dynamite must be accomplished with consideration and according to the laws regulating such transport. High explosives and detonators should not be carried together in the same vehicle, and neither may be carried in a vehicle carrying passengers. Trucks must display conspicuous signs warning the public that explosives are being transported.

Procedures And Methods In Using Dynamite

The remainder of this section describes proper methods of using explosives under the conditions most likely to be met by the Alaskan prospector.

PREPARATORY WORK - The preparatory work is done before the dynamite is brought to the site. Holes are drilled and cleaned out, stemming is procured, and a safe place picked to which the blaster retreats during the explosion. Just enough dynamite to do the job is taken to the site and, although it is quite insensitive to shock, it is handled carefully. Dynamite boxes are opened with a wooden wedge and a wooden mallet, never with metal tools.

PRIMERS - When the site is reached, the prospector makes up as many primers as there are holes. A primer is a stick of dynamite in which is imbedded a blasting cap attached to a length of fuse (or wires, if electrically fired). A piece of safety fuse at least two feet long is cut off with perfectly square ends. This is done by knife or with the cutters on the cap

crimpers. Cold fuse should be allowed to warm as it may be brittle, causing it to break. When several shots are to be fired in a fixed order or in rotation, all fuses are cut the same length and trimmed later. (Most is trimmed from the fuse which will set off the first shot, and each succeeding fuse is trimmed slightly longer than the preceding one; nothing is trimmed from the last. They are then lit in the order in which they are to go off). The amount trimmed from any fuse should never be less than ten per cent of the length of the shortest fuse, as the speed of burning may vary this much. A cap is slipped over the end of the fuse and crimped with a cap crimper about 1/8" from the end of the cap. This procedure gives a moderately waterproof joint which will not allow the fuse to pull out of the cap. If it should pull out, or if the end of the fuse is not cut squarely, or if the end of the fuse has been damaged so that powder has spilled out, the cap may not fire. Misfires (unexploded shots) which must be dug out or exploded, are the cause of more accidents than rough handling. Boot legs, which may cause unexploded dynamite to be thrown into the muck pile, are not so dangerous, but obviously should be avoided. Caps are never crimped with the teeth. Crimping with ordinary pliers does not make a strong nor waterproof joint. When very wet work is encountered, waterproof fuse is used, the very best crimps are made, and the joint between cap and fuse is waterproofed by dipping the joints in special waterproofing compound or even coating with soap or heavy grease. Sealing wax or other compounds which require heating, of course, cannot be used safely. The capped fuse must be imbedded in the dynamite so that it will not pull out. This is sometimes done by punching a hole diagonally through the cartridge, then another diagonal hole part way through. The capped fuse is laced through the first hole, then pushed into the second. The lacing effectively holds fuse to cartridge without the necessity of tying the fuse with string and is almost universally practiced.

There are other conditions which must be satisfied to make a good primer: the fuse must not be kinked, it must be in such a position that it will not be damaged in tamping, and the cap must be imbedded in the center of the cartridge. Lacing, if done in smooth curves, satisfies these requirements because the fuse enters on the side of the cartridge where it will not be kinked by the tamping stick.

Another method of making a primer is to punch a hole diagonally in the side of the cartridge into which the fuse enters, the cap lying in the center of the cartridge, parallel to the long axis. The fuse is then tied to the cartridge with string. A third method is to insert the cap in the end of the cartridge, double it back, and tie the fuse to the cartridge with string. This has disadvantages. The fuse makes a sharp bend and issues from the cartridge in a position where it could be kinked in tamping.

Holes are most safely punched in dynamite with a pin of wood, brass, aluminum, or other non-sparking material, although a steel punch on the handle of the crimper often is used. Some of these punches are curved, so the hole can be started diagonally into the side of a cartridge and curved around until it is parallel with the long axis of the cartridge.

When electric blasting caps are used, a hole is punched in the end of the cartridge, the cap inserted, and the wires brought back alongside the cartridge. The easiest method of securing the cartridge to the wire is to take one or two half hitches around the cartridge with the wire. Because electric blasting caps are detonated by a current of 0.3 amp., or even less, it is very important that blasting with such caps is not carried on where there is danger of stray ground currents. Electric caps should not be used when an electrical storm approaches within five miles, nor around broadcast stations, nor while small radio transmitters are operating nearby, nor in any locality where it is suspected that static electricity or small transient ground currents exist.

For rotation firing, delay electric blasting caps are used. These have a quantity of powder between the electric igniter and the detonator. How long a delay occurs between the electric impulse and the detonation depends upon the length of the powder train. These caps are inserted so that there are progressively longer delays for later shots.

When primacord is used to prime a charge, it is not imbedded in a cartridge. It is desirable for it to extend the full length of the charge, so it is tied to the first cartridge inserted in the hole, and the other cartridges are pushed alongside of the primacord. Fig. 16-7 shows some different ways of making primers.

PREPARATION OF CHARGES, HANDLING OF MISFIRES - Although there are certain acceptable safe methods of preparing charges, the details vary depending on whether primary or secondary breakage is involved.

Primary Breakage - (Primary breakage refers to breaking bedrock, as distinct from secondary breakage of boulders or fragments). After the primers are made up, it is time to prepare the charges. If drill holes, either in bedrock or in a boulder, are to be loaded, the dynamite must be made to fill the hole completely. More efficient use of the explosive, better breakage, and fewer fumes are the result. Cartridges are pushed into the holes with tamping poles, round wooden rods of the same diameter as the dynamite. Tamping poles must have no exposed metal parts. If perforated paper wrappers which burst under pressure are not used, the wrappers are slit lengthwise to within an inch of each end just before being inserted in the hole. Two such slits are made on opposite sides of the cartridge. When the cartridge reaches the end of the hole, it is tamped with light blows of the stick to insure its spreading

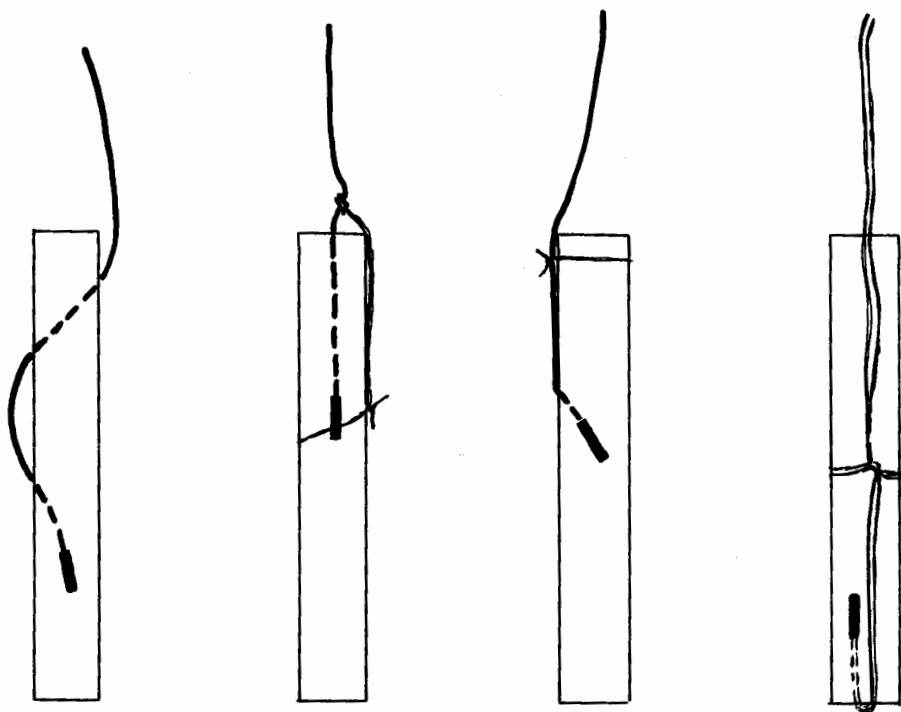


Fig. 16-7. - Four Ways of Making Primers. Electric Blasting Cap on Right.

and filling the hole.

If only one stick or less is used, it is in itself the primer, and it is carefully pushed into the hole. The primer should never be tamped. If several holes are to be blasted in rotation, there is a chance that the outer portion of a charge may be blasted into the muck pile by an earlier blast. If the primer is in this outside portion of the charge, the prospector will be faced with the double danger of a primed cartridge in the muck pile and an unexploded charge in the hole as well as having a poorly executed blast due to the failure of one charge to explode. For this reason, when more than one charge is to be exploded, the primer must be placed near the inside of the charge.

Another reason for placing the primer near the back of the hole is the decreased danger to the prospector should he need to clean out the stemming if the shot misfires. Stemming is any inert material used to fill the hole above the explosive. Clay, silt, sand, or loam are best; rock dust and cuttings are sometimes satisfactory. Stemming should be cleaned out with a wooden or copper instrument, pointed on one end and spoon shaped on the other. The stemming is carefully broken up with the point and pulled out with the spoon, a little at a time until the dynamite is reached. A cartridge or half a cartridge of the strongest dynamite available is then primed and pushed firmly against the charge, after which the hole is stemmed as tightly as possible to direct the force inward. If water is available, the least dangerous way to remove stemming is to wash it out with a hose, but this method ruins the dynamite if it is not water-proof. If electric caps are used, the wires should be shorted before starting work. Working on misfires is the most dangerous job in blasting.

In a hole of a diameter less than that of a dynamite cartridge, the paper shell is opened up, the contents molded (never tamped) into the hole, and a cap, with its projecting fuse, imbedded near the upper end of the charge.

The remarks applying to the position of cap-and-fuse primers, of course, apply equally well to electric cap primers. If primacord is used, it should extend to the bottom of the hole and be in contact with the charge through its entire length.

It has been mentioned that most results sought in blasting are improved if the charge is confined. This confining is done by stemming. Combustible material must not be used; the only

exception is the use of quick seal plugs, asbestos rings which are expanded by a conical wooden wedge to seal the hole. Stemming is tamped tightly with the tamping pole, after which the charge is ready to fire.

Secondary Breakage - Secondary breakage is the breaking of boulders or fragments resulting from a primary blast. There are four methods of blasting boulders. The first, blockholing, is similar to the method just described for blasting in rock. A shallow hole is drilled into the rock, loaded with about one half stick of dynamite, and stemmed. The second, snakeholing, is also similar except that the explosive is charged into a hole punched in the dirt below the boulder. The third, mudcapping, consists of laying two, three, or four sticks of dynamite on the rock and covering with about four inches of mud or damp clay. If the boulder can be pried up and one side rested on a rock so that it is unsupported in the middle, better breaking is attained. Sometimes the dynamite is removed from the wrappers and molded. The wrappers are used to cover the dynamite and keep it from getting wet. Slightly better breakage has been reported if the dynamite is molded into a rough paraboloid before being covered with mud. The fourth method of secondary breakage is the use of a recent development called the shaped charge: a charge of dynamite enclosed in a cardboard or plastic container. The container is so shaped that most of the blast is directed downward into the rock being broken. Better breakage per pound of dynamite is attained than by mudcapping, but much less than by blockholing. Labor costs, however, are much lower. Shaped charges are detonated in the same ways as ordinary dynamite. The relative efficiency of blasting boulders by mudcapping, snakeholing and blockholing can be seen by the following figures from duPont's Blaster's Handbook.

Table 16-1

Charges for Boulder Blasting

Diameter of Boulder in Feet	Approximate number of Cartridges, 1 1/4 " x 8" in average hard stone required for:		
	Mudcapping	Snakeholing	Blockholing
1 1/2	2	1	1/4
2	3	1	1/4
3	4	1 1/2	1/2
4	7	4	3/4
5	12	6	1

Experiments in blasting boulders by the Research Department of the School of Mines, University of Alaska, in 1954 at Fairbanks, showed the following results:

Table 16-2

Method	Average Cost per ton of rock blasted
Shaped Charges	\$2.07
Blockholing	\$1.49
Mudcapping	\$2.21

The boulders were of granodiorite, two to four feet in diameter. Holes were drilled with a Warsaw gasoline drill. Other factors, such as whether enough work is available to justify the purchase of a drill and the increased fragmentation when blockholing, must be considered also.

FIRING - After the charges are in place, completely primed and stemmed, they are ready to be fired. If they are to be fired electrically, the cap wires are twisted to lead wires connected to the blasting machine at a safe distance. If rotation firing is to be done, delay electric blasting caps are used. Bare wire splices should be kept off the ground, and if this is impossible, as where the wires pass through stemming, the splices should be taped.

Electric caps may be set off by blasting machine from power lines or by portable generator. The prospector, if he uses electric caps, almost invariably uses a small blasting machine to detonate them. These machines are given numbers corresponding to the number of caps which they will detonate. A small twist type, "No. 10" is sufficiently large for most rounds, although the push type machines are available which will set off 200 caps. Either the twist type or push down type should be operated with as much strength as the operator can muster.

Most likely the prospector uses safety fuse. After trimming the fuses and determining in what order they are to be lighted, the ends are cut to expose the powder core. This exposure is done by splitting the fuse for about one half inch from the end or by making a diagonal slash part way through the fuse near the end. When the fuse ignites, the flame shoots out the end with a hiss. This is the spit, and often is the only indication that the fuse has been lit.

Quick, effective lighting of safety fuse requires a hot flame. If matches are used, the initial flash of the match should be used. Sometimes the match head is held at the split fuse and a

piece of metal drawn across the match; sometimes a match head is embedded in the slit and lit with another match. Ordinary match flames or candle flames often take so long to ignite the powder that they are not safe to use if more than one fuse is to be lit. The acetylene flame from a carbide lamp provides a hot concentrated flame ideal for lighting fuse but involves one danger, which also applies to the use of candles. If the light is dropped while the round is being lit and goes out, the prospector may have to leave the round half done and grope his way to safety in the darkness. If two men work together, this danger is eliminated.

The best lighters are those made especially for the purpose. Some of these are as follows. The lead spitter is a coil of tubing filled with powder which burns with a continuous spit of flame. The hot wire is similar to a fireworks sparkler. The match lighter is a paper tube which slips over the fuse and has one end coated with the same substance used to make safety matches. The pull wire fuse lighter is a paper tube which slips over the fuse and is ignited by pulling a wire. The master fuse lighter is a shell into which are slipped the trimmed ends of a round. It contains an igniting substance which lights all the fuses at once and which in turn is ignited by a single fuse. A contrivance which gives excellent results after a little practice, is a spitter, a length of safety fuse with gashes in its side every few inches. As the flame reaches each gash, it spits out the side with an intense heat. The spitter is held in such a way that the spit of flame ignites the fuse being lit. If there are nine shots to a round, nine slashes are used. The spitter also serves as a timer. If it is determined that the blast site must be left at the latest when two feet of fuse is still unburned, and the first fuse lit is five feet long, then a three feet length of fuse lit at the same time as the first fuse, can be a timer. When the timer has burned completely through, the prospector must leave, whether he is ready or not. Usually there is plenty of time to spare, but the timer protects against losing track of the time and consequently harrying too long near the blast.

After lighting the fuse, the prospector retires to a place of safety from which he can warn away any persons who might accidentally wander too close. If the blast is underground, he should go to the surface unless an opening is so located that all fumes will be carried away. This is very important; if caught in the direct path of the fumes, the blaster could be killed. For the same reason, the scene of the blast, if underground, should not be visited for several hours unless artificial ventilation is provided. Spraying the muck pile with water helps settle dust and displace fumes which are forced into the air and carried away.

Blasts in a round are counted as they go off; if they do not all explode, the face should not be visited for a length of time sufficient to assure that the charge cannot be exploded by some delayed action (one hour in the absence of specific rules). Counting of shots should not be relied upon entirely for detection of misfires; the blast should be inspected carefully to make sure that none exist. Care should also be exercised when mucking the round in case dynamite has been blasted into the muck pile. The handling of misfires has already been described, and it is sufficient here to state that the dynamite itself is never dug out. The stemming is dug out, a new primer inserted, and the misfire exploded. The cap should be in such a position that it cannot accidentally be touched by the tool as the last of the stemming is removed. The tool should be of some non-sparking material.

Sometimes a hole is sprung, that is, enlarged by blasting so that a larger charge can be placed in it. When springing, the hole must be left for several hours before it is reloaded. Otherwise, the high temperature of the rock resulting from the previous blast may cause the second to explode. Men have been killed by this type of accident.

CONCLUSION - Most written discussions of explosives end with a list of "Don'ts" DuPont's "Blasters' Handbook" and the sheet inserted in every box of dynamite lists over 60 "do's" and "don'ts". Here it is sufficient to say that the handler of explosives should bear in mind at all times that his life depends upon his judgment and competence, and he should act accordingly. One final word upon the subject: almost any operation described in this book may be performed by the beginner after merely reading about it. The use of explosives is different. No matter how many dissertations upon blasting have been read, the use of explosives should be preceded by actual instruction by and observation of an experienced blaster.

BLACKSMITHING

The prospector is continually faced with the necessity of sharpening his digging tools, and he occasionally may need to produce iron or steel implements. For these reasons some knowledge of blacksmithing is essential.

Tools and Equipment

A blacksmith must have a means of heating iron and steel, a means of working them, and a means of tempering. For the isolated prospector, these may be as simple as a wood fire, a hammer, a large stone, and a pool of water. Such an outfit allows him to sharpen picks or small handsteel occasionally, but if he is to sharpen anything larger, he needs a forge and an anvil, tongs, files, and a supply of coking coal or charcoal.

A forge consists of a low walled container, called the hearth, which holds the fire, a tuyere, through which air is introduced to the bottom of the fire, and a blower or bellows to create a current of air which is conducted to the tuyere. The cupped air outlet of the tuyere is called the duck's nest. A tuyere may be improvised by squeezing together the end of a short length of two inch pipe and hack sawing two cuts through about a third of the diameter of the pipe just behind the flattened end. The metal between the two slits is pounded down, leaving an opening through which air can escape. The pipe is laid in the forge so that the opening is upward. Another type of improvised tuyere is made by drilling several small holes in a cluster in the center of a two foot length of pipe. One end of the pipe is connected to the blower; the other is stopped with a wooden plug which may be removed at any time to clean ashes from the tuyere.

In a permanent blacksmith shop the hearth is built of brick or of wood with low walls surrounding it. Clay is packed into the hearth with a duck's nest left around the tuyere. Most forges used by prospectors are of steel, built in factories and transported to the site; these forges are self contained, consisting of a hearth on legs, tuyere, and blower. However, forges may be improvised to meet different conditions. Churn drills using heavy bits usually are supplied with a tuyere and a blower driven by the drill engine. The tuyere is placed in a hollow in the dirt, and air is conducted to it from the blower through a canvas hose, pipe, or even an old inner tube wired to the blower outlet and the tuyere inlet. Such an arrangement serves well when heating heavy bits which otherwise would require supporting at the level of the forge. To keep the coal from becoming scattered and mixed with dirt, it is sometimes desirable to use an old dishpan or similar utensil for a forge. The pan is laid upon the ground, and the tuyere set inside it or beneath it, with a hole cut in the pan so that the air enters from below.

When a forge is located inside a building, the smoke must be led away. The best means of doing this is to have a large flue located as close to the fire as practical without interfering with the work. If a small opening is made in the flue, a strong draft will blow through it, removing smoke and dust before they have a chance to rise.

The anvil for ordinary work should weigh, if possible, at least a hundred pounds, but a smaller anvil will serve; even a piece of steel rail can be used if necessary. For stability, the anvil should rest upon a solid block or section of tree trunk sunk two feet in the ground. A light anvil must be fastened to the block with lag screws and straps. The anvil should be level with the blacksmith's knuckles when he stands beside it.

The face of the anvil is hardened, and because it may be chipped, it should never be struck directly with a hammer. Projecting out from one end of the anvil is the horn for forging curved work. A step between the face and the horn is softer than the face; work being cut by chisel is laid on the step. A square hole in the anvil takes the shanks of several special tools. The most useful of these is the hardy, a chisel-like cutter with a sharp edge projecting upward. Hot iron or steel to be cut is laid upon the hardy and hammered. The hardy is not tempered, but it is kept sharp. The shank of the hardy extends through the tail of the anvil so that it can be hammered up if it sticks in the hole.

The tools which are used with the anvil come in pairs; one of the tools of each pair is fitted with a shank to fit in the hole in the anvil, and the other is fitted with a handle. Thus the counterparts of the hardy are the hot cutter and the cold cutter, both of which are held in the hand by a wooden handle and struck upon the head with a hammer. The flatter has a flat surface which is laid upon the work and struck. A swage has a concave grooved surface for certain types of forming, and a fuller has a convex sectioned surface. Tongs having different shapes to facilitate holding different types of work should be on hand.

For sharpening churn drill bits, a billet and anvil block is necessary. The billet is a timber about four inches by six inches, a little longer than the bit. At one end is a block of steel (the anvil block) having two pins on its lower side to engage two holes in the billet, and at the other end is a block of wood with a socket cut into it to take the pin of the bit. The wooden billet has a series of holes at different positions along its length so that the anvil block can be moved from place to place to accommodate bits of different lengths. The cutting edge of the bit rests upon the steel anvil block. A round bit gauge or a caliper is needed for dressing the bit to size.

A shop may have a work bench, vise, post drill, and other accessories, but for sharpening tools the only accessory besides the forge, anvil, and hammer is a tub of water, called a slack tub for tempering. For heavy bits it is useful to have a rest in the tub, upon which the bit can be set so that it will be tempered in shallow water, while still having the benefit of a large volume of water for cooling. A perforated plate elevated off the bottom keeps bits from cutting the tub, and keeps them out of any sludge in the tank.

Raw Materials

Iron, to the chemist, is the pure metallic element symbolized by "Fe". When iron ore, limestone, and coke are burned together in a blast furnace, a liquid product is obtained which contains about 90% iron 3.5% carbon, and the remainder phosphorous, sulfur, and other impurities.

This product is pig iron. When pig iron is remelted and cast into useful shapes, it is cast iron, hard and brittle because of its included carbon and impurities. Cast iron is kept at a white heat for about a week to burn out most of the carbon and impurities. Castings so treated will withstand some bending and are said to be made of "malleable cast iron".

Another useful form of iron is wrought iron, made by melting pig iron in a puddling furnace in the presence of iron oxide, usually scale. The impurities and the carbon are oxidized by the oxide and removed. The iron becomes pasty as the carbon is removed; and it is worked into a ball on the end of a rod, removed, and squeezed in a press to remove most of the slag which was entrapped during the "puddling". Wrought iron is essentially pure iron with a considerable amount of admixed slag. It is malleable and is used for ornamental iron work and other purposes which require good malleability.

Iron finds its greatest use, however, as steel. Steel is a term which embraces a wide assortment of iron products having many different qualities, but basically it is iron which has been purified and which contains a smaller amount of carbon than does cast iron (from 0.03 percent to 2.5 percent). Most tool steels contain between 0.5 percent to 1.3 percent carbon. The steel contains other constituents as impurities, but they do not affect the desired qualities appreciably. Such steel is called simply carbon steel. Alloy steels are carbon steels to which have been added one or more other elements for the purpose of achieving some special quality.

Mild steel, used for making wire, sheet, plate, rails, and other products which make up the bulk of our steel consumption, is low carbon steel, containing a small amount of inexpensive alloying elements. Mild steel is made in the Bessemer converter or the open-hearth. The Bessemer converter is a bricklined retort into which the iron is charged. Air is forced through the molten iron until the impurities are burned out and the carbon content is reduced to 0.3 percent or less. After the blowing is stopped, the steel is full of oxygen, which is removed by adding a small amount of other elements mainly silicon and manganese.

In the open-hearth furnace, the amount of carbon and impurities is reduced by oxidation; but the oxygen is introduced not by supplying air but by adding iron ore (which contains oxygen). When the desired carbon content is reached, deoxidizers such as manganese, aluminum, or silicon, are added. Most steel produced in open-hearth furnaces is low carbon mild steel, but a considerable proportion is higher carbon steel (with or without other alloyed elements) which is used for such things as springs, machine parts, and hand tools.

This higher quality steel comes under the heading of tool steel, although the best tool steel is made by further processing the products of the Bessemer or open-hearth furnaces. Although tool steel has been made by different processes, in modern practice either the crucible or carbon ore process is used. Crucibles are charged with pure iron and enough refined pig iron to yield a mixture of the proper carbon content; if desired, the alloying constituents are added at the same time. Most tool steel is now made in electric arc furnaces in which the heat is produced by arcs jumping between large carbon electrodes very close to the melt. These furnaces are charged either with scrap or pure iron or with molten steel from a Bessemer or open-hearth operation.

It has been stated earlier that tool steel contains more carbon than does mild steel. Plain carbon tool steel contains from about 0.50 percent to about 1.30 percent carbon. Carbon steel becomes harder as the amount of carbon is increased, up to about 0.30 percent; after that point, adding more carbon does not cause the steel to be harder but increases the resistance to wear.

When no plain carbon steel can be found to fulfill a particular requirement, an alloy steel may have to be used. A few elements may be present in carbon steel in small quantities without the steel being considered an alloy steel. Thus it will be recalled that small amounts of manganese, aluminum, or silica are added to mild steel to deoxidize it in the open-hearth furnace. The true alloy steels, however, are those to which new elements have been added specifically to introduce a new quality or to accentuate qualities already present in the carbon steel. The following elements are used as alloying agents: tungsten, manganese, nickel, chromium, vanadium, molybdenum, cobalt, aluminum, silicon, phosphorus, and sulfur. Of these, tungsten, manganese, nickel, and chromium are most important. Phosphorus and sulfur are, in general, harmful.

Tool steel is cast into ingots which are inspected for impurities and defects. Any cavities or other imperfections are cut away so that what remains is solid steel. The ingots are then rolled or hammered into billets, which after having been cleaned, annealed, and inspected, are ready for the toolmaker or blacksmith.

Heat Treating

The first thing the smith must know is how to build a fire. A small fire is kindled with shavings or oil-soaked rags in the duck's nest, dry coal is piled around it, and a light draft provided until the coal ignites. More coal is then banked up completely around the fire, wet down, and patted to form an air tight crust on the surface. The purpose of this procedure is to confine the fire to the center and to provide the right conditions for producing coke, for although coal is added to the fire, coke is burned. The coal used must be coking coal, and since coking coal is found in few localities in Alaska, blacksmith's coal produced in the Eastern United States is usu-

ally purchased and hauled to the site of operations. The fire can be made smaller by packing the damp coal tighter around the center or enlarged by allowing the coke to dry out over a bigger area and by punching air holes in the dry coke area with the poker. Damp coal is added from the outside, and water is occasionally sprinkled around the periphery of the fire. The mound of coal should not be allowed to become too flat but should be piled up all around the fire. The fire should be two to four inches deep, or deep enough so that the steel to be heated has burning coke above and below it. If a long fire is needed, it can be made by piling coal on two sides instead of all around.

If coal is not available, charcoal may be used. Charcoal is perfectly clean and makes a hot fire, but its preparation requires a considerable amount of time and labor. Charcoal is made by burning wood in an atmosphere lacking in oxygen. This may be done in several ways, but one of the simplest is as follows: the wood is cut about eighteen inches long and split. A circular shallow pit is dug one to two feet deep and four to eight feet across and the wood piled into it, beginning with a few sticks standing on end, with successive sticks standing on end but leaning toward the center around those in the middle. Another, smaller pile is made on top of the first, and another on top of that, so that when finished, the wood pile looks like a cone. The wood must be piled loosely so that air can circulate freely. The whole is covered with sod, leaving only a few small holes around the perimeter of the base and a larger one on top. The wood is fired from the smaller holes, and when the fire burns briskly, all holes are almost completely covered. It is allowed to smolder four or five days, then is uncovered and the charcoal packed in sacks or boxes. Charcoal, when burned in the forge, is not coked but is fed directly to the fire.

If small tools, such as picks or moils, are to be sharpened and no forge is available, a fire of bark, dead willows, or alders burning in a stove can be hot enough. This substitute is unsatisfactory but one which often must be resorted to.

A forge fire dies unless tended continuously. If it is necessary to leave the fire, it can be kept burning for a few hours by placing a piece of wood about two inches square in the duck's nest and covering it with coal.

FORGING OPERATIONS - The prospector does not often find it necessary to forge articles from iron or mild steel; consequently, only a few pointers to guide him in such work are given. The steel must be heated uniformly to a temperature which produces a light yellow color and worked upon the anvil with strong blows, which become lighter as the work cools. When the temperature has dropped below the critical point (see page 312) the work is returned to the fire. Care must be taken to avoid heating the steel so much that it burns, as indicated by white sparks flying from the metal. The danger of burning is much less in mild steel than in high carbon steel.

The forging of mild steel into useful shapes involves only seven operations: drawing, upsetting, bending, punching, riveting, scarfing, and welding.

Drawing is the process by which iron or steel is made smaller in cross section by hammering, turning the steel 90°, and hammering again. Care must be taken to turn the steel exactly 90° or a diamond shaped cross section results. The heat for drawing must penetrate uniformly to the center of the metal; otherwise the metal will be drawn out more rapidly on the outside than on the inside, and stresses will be set up in the steel.

Upsetting means enlarging the cross section of the steel by hammering on the end to expand the metal at the heated part. If the work is of such size or shape that it cannot be hammered conveniently, it may be dropped on the top of the anvil or butted against the side.

In bending, the only precautions to be taken are to make sure the metal is hot enough to be bent easily. A piece with sharp corners, which might be marred by hammering, may be bent with a mallet.

In punching, the blacksmith makes holes in hot metal by causing it to flow out of the way of the punch. The hot iron is placed on the face of the anvil and the punch driven down to where the work feels solid. The work is then turned over and the hole finished from the other side over the hole in the anvil. Punching should not be done to a piece of metal which must hold its shape accurately because the metal which flows away from the hole enlarges the piece somewhere else.

Riveting requires little special mention other than that rivets should not be so long as to swell or buckle in the middle. Rivets should be hammered with light blows. If a rivet must be made, a piece of round stock is taken, the diameter of which is big enough for the head. The point where the shoulder is to be is placed at the sharp edge of the anvil, and the shank of the rivet is drawn out on the face of the anvil. Rivets are never quenched, for even if made of mild steel, there may be enough carbon present to cause them to harden.

Scarfing is the shaping of iron for making forge welds. The ends which are to be welded are first upset to insure that there will be enough metal to allow for losses in heating and welding. They are then forged so that they each taper at about 30° and overlap each other with a slanting contact line. The slanting faces should be slightly convex so that they touch each other only in the centers.

Although welding in the forge is seldom done any more, it may be necessary under certain

conditions. The surfaces to be welded are heated white hot, a temperature at which they begin to flow. They are then quickly joined together in the proper position and hammered. The difference between welding temperature and burning temperature is slight, especially in tool steel, and care must be exercised at all times. The surfaces to be welded must be kept clean. Clean silica sand or borax is sometimes used as a flux in welding; the flux melts and protects the surface of the metal from air, without which the steel cannot burn.

SHARPENING TOOLS - As the prospector's digging tools become dull, they must be sharpened by being hammered hot and re-hardened. After the fire is burning in the forge, the tool is inserted and heated. It is heated well above the critical temperature (for ordinary steels this temperature is from 1364° to 1670° F, see page 312), yet not so high that the steel is burned. Burning steel is indicated by white sparks flying from the surface. High carbon steel burns more easily than low carbon steel. The proper temperature is judged by the color, which should be "cherry red". The steel should be turned over in the fire occasionally and otherwise maneuvered to produce an even heat. Hammering affects the grain size and shape; consequently it can have an improving or injurious effect upon the steel.

Hammering should not be continued after the temperature is below the critical point or severe stresses liable to cause cracking will be set up. Blows should be heavy enough so that the internal metal is made to flow as well as the surface metal. Pointed or wedge shaped tools should be hammered with glancing blows, the hammer striking the steel in such a way that steel is drawn toward the bit. During this hammering, the steel usually flows in other directions enough to bring the tool out to gauge. If it is necessary to hammer the edges of a tool to narrow the gauge, it should be done to draw the excess metal toward the cutting edge, not so as to drive it back into the tool. Tools forged in this way do not have surfaces of weakness along which fractures can occur and are much superior to tools in which the steel has been hammered back and forth. Hammering after the steel has cooled below critical temperature also causes planes of weakness to develop.

All tools except churn drill bits and cross bits are sharpened on the anvil. Cold chisels and mauls may be sharpened with a file while they are hot or after they have been shaped and before they are hardened. The best all-around angle of penetration for cutting edges on rock cutting bits, whether used in hammer drills or churn drills, is about 90°. The cutting edge may be pointed somewhat more than this for soft rock, but if too sharp, the bit penetrates too far and sticks; or if it does not actually stick, at least it wastes energy through penetration without breaking. Too blunt an angle results in crushing rather than breaking. The bit, of course, must flare out so that the cutting edge has a greater diameter than the shank. If it does not flare, the bit cuts a hole the same size as the shank and sticks in the hole. However, the corners of the cutting edge, which do most of the cutting, wear faster than any other part of the bit, and when the corners have worn appreciably, the cutting edge no longer is the widest part of the bit. Bits intended for drilling fairly soft ground may flare out to sharp corners, having an angle of clearance. Such a bit is said to have a feather edge and is reduced in gauge too rapidly to use on hard rock. For hard rock drilling, a wearing surface is left on the bit. This surface is above the corners, has the same diameter as the corners, and provides shoulders to give them strength, as illustrated. Such a bit has no angle of clearance. When the corners become dull, the wearing surfaces tend to stick, but they provide the steel necessary to keep the gauge from being reduced too rapidly. These different cutting edges are illustrated in Fig. 16-8.

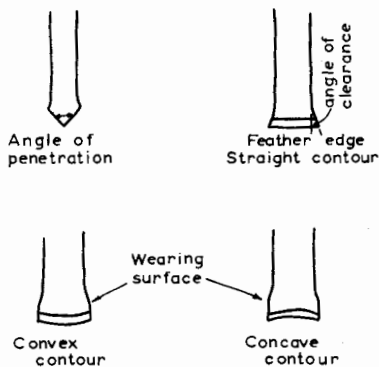


Fig. 16-8 - Cutting Edges of Bits

The contour of the penetrating edge may be concave, straight, or convex, and which type is adopted seems to depend upon the likes and dislikes of the driller. A concave contour is favored by many because it provides extra steel at the corners.

Churn drill bits are heated with frequent turning in the forge and are laid on the billet block. One man kneels near the pin end of the bit, ready to turn it at a word from the bit dresser. The bit dresser strikes with an eight to twelve pound blacksmith's sledge, working as fast as possible while the bit is hot. He checks the gauge with a steel bit-gauge in the form of a ring having a diameter slightly less than the inside diameter of the casing. Corners may be dressed with a lighter hammer.

If the bit has water channels, they should be kept clear and not allowed to fill with steel during sharpening. They may be peened to drive the steel back into the bit, or the excess may be cut out with a cold chisel.

Steam points are forged and tempered as are

picks. If the steam hole becomes closed, it is opened up with a punch.

After the tools have been hammered back to the proper shape and size, they are still not ready to use, for they are now so soft that they would bend rather than cut if placed in operation. Different tools require different steels, but most tools used in prospecting are made of plain carbon steel. As indicated under "Raw Materials," this steel consists of a small amount of carbon mixed with pure iron. Tools such as those used to cut rock require greater hardness than those such as punches, chisels, or knives. The harder tools are made from steel having a higher carbon content than the softer ones.

The prospector, of course, cannot vary the carbon content of the steel in his tools, but he has available the means to vary its hardness, toughness, and brittleness within the limits set by the carbon content of the steel in any one tool. The above named properties depend upon the crystal structure of the iron, the distribution of the carbon, and the grain size. All of these can be varied by different processes of heating and cooling, called heat treating. This heat treating generally consists of two steps, hardening and tempering, and can be accomplished with the simple equipment of the blacksmith.

Hardening can be understood from the following: when a steel is heated to a temperature above its critical temperature, the iron in the steel changes to a different crystal form, which, with its dissolved carbon and iron carbide, is called austenite. The exact critical temperature depends upon the amount of carbon in the steel and occurs at a red heat, somewhere above 1300°F. If the steel contains about 0.8 per cent carbon, it is converted to the new form shortly after reaching the critical temperature of 1364°F; but if it contains more or less carbon, it must pass through more critical points and consequently be heated to a higher temperature. It must be maintained at the hardening temperature for some time for complete transformation to take place.

If the steel is now slowly cooled, as it passes through the critical temperatures in the reverse order, the changes occur in reverse order, although at lower temperatures, and the cooled steel has a composition somewhat like it had at the start. This is called annealing, and if properly done, leaves the steel refined and without internal stresses, although still soft. Such steel is called ferrite.

If the steel is cooled quickly below the critical temperatures, as by quenching in a liquid bath, the austenite cannot convert back into the softer, more ductile tougher forms but converts to hard brittle forms, predominantly martensite. This process is called hardening. In the low and medium carbon steels, increasing the carbon content causes the steel to be harder after quenching. Adding more carbon above about 0.8 per cent will not cause the steel to become harder but increases its wearing resistance. A cooling rate intermediate between annealing and quick-quenching to martensite produces pearlite, part way between ferrite and martensite in hardness.

Many different liquids are used for quenching, but in blacksmithing, clear water is most common. Bubbles, however, may form in water when heated by the hot steel; and where a bubble is in contact with the steel, the steel does not cool properly. Salt added to the water prevents bubbles and provides a more even quenching. The proper concentration is about 3/4 pound of rock salt per gallon of water; more salt than this amount causes the cooling to be too slow. Water must be added to maintain the proper concentration as evaporation proceeds. The temperature of the quenching bath should be kept at 70° - 100°F. Steel should be quenched as its temperature is rising. It should never be quenched on the same heating as was used for forging but should be allowed to cool until it stops glowing, then reheated.

The steel, after quenching, has its maximum hardness but is brittle and is stressed internally because martensite occupies a different volume than do other forms. For some tools this fact does not matter, but for most, further treatment is necessary. To decrease brittleness, relieve stresses, and impart toughness, the blacksmith must heat the steel again, this time, for most steels, to a temperature lower than the hardening temperature. This process is called tempering, or drawing. As the steel is reheated, the hard, brittle martensite begins to change into a softer tougher form called tempered martensite. By stopping the process at any point, the blacksmith may achieve a ratio between the brittle and the tough to produce a steel to meet the particular requirements of the tool being worked.

In tool factories, steel is heated for hardening in a furnace held at a known temperature or in a hot liquid bath. It is heated for tempering in either of these or on a hot steel plate. The correct temperatures are determined experimentally, and accurate temperature control is maintained at all times. When the steel reaches the desired tempering temperature, it is removed and allowed to cool slowly in the air, a process called normalizing, or the furnace is allowed to cool with the steel in it, which has the desired effect. Heating to a known temperature followed by slow cooling gives the proper brittle-tough ratio; stresses are relieved, and no new stresses are introduced.

Unfortunately, the blacksmith must work with an open flame, with which it is difficult to maintain accurate temperature control. In hardening, the blacksmith judges the proper temperature by color: cherry red. Obviously the temperature required to produce a cherry red is greater on a bright day than on a dull day, but fortunately the hardening temperature is not

critical, so long as the steel is heated above its uppermost critical temperature and held there long enough to allow the steel to be converted to austenite. The temperature should be uniform across the cutting edge so that no differences in hardness result. (If one side is hotter, it may be cooled by touching it to wood, damp rags, or other material). The steel is removed from the fire, and the cutting edge plunged into the slack tub. Here it is agitated up and down so that no sharp line of demarcation will exist between the hard and the soft steel and moved around to get into cold areas. If the steel can be used plunge hard, as it can in most drill steel for hammer drills, it is left to cool in the water.

When it is necessary to temper a tool, as it is in most cases, the problem is more difficult because the tempering temperature is more critical than the hardening temperature. In the forge it is possible to reheat the steel after hardening, but it is impossible to tell when to remove it because the tempering temperature occurs before the steel begins to glow. Therefore, a different method is used, one which produces good results when used by an experienced smith. When it is considered that much time is saved by its use, the method to be described probably is economically superior to furnace tempering for the simple tools used by the prospector.

When the tool is removed from the fire after it has been heated for hardening, it is immersed so that only the steel for a short distance back from the cutting edge is under water. It is quenched for a few seconds or until it has reached a temperature slightly cooler than boiling water. Care is taken to keep the tool moving up and down and back and forth in the quenching medium. The tool is then withdrawn, and the cutting edge allowed to heat up by drawing heat from the body of the tool, which was not quenched. In carbon steel, different oxide colors form on the surface at different temperatures within the tempering range. The scales and soot are removed from the surface of the tip by scraping it in dirt or on a file or stone, and the tip is observed closely for color changes. As the heat advances from the shank toward the tip, a band of colors is seen advancing with it, each color corresponding to a different temperature. First, at the coolest (forward) end of the band will be a faint straw color, grading into straw, bronze, purple, blue and light blue. When a particular color reaches the tip, it indicates that the surface at that instant has attained a particular temperature and so a particular ratio of hard to tough components. The only way that a further increase of temperature, and consequently further softening of the steel, can be stopped is by plunging the steel and leaving it to cool. This process introduces some new internal stresses, although not seriously, because the quenching is done below the critical temperature, and very little martensite is formed. These stresses may be further eliminated by a second tempering operation.

The temperature-color relationships are approximately as follows:

Faint straw	400° F
Straw	450° F
Purple	540° F
Blue	575° F
Light Blue	640° F

All tools intended for cutting stone, which include picks, handsteel, moils, churn drill bits, steam points, etc., are tempered to a straw color heat. Cold chisels are tempered to a blue color heat, and knives, hammers, and twist drills are tempered to a purple color.

Small tools, such as knives or small chisels, may be heated for tempering by pinching between a pair of red hot tongs.

One tempering job which deserves special mention is that of a churn drill bit. Because of its great bulk, the inside of the steel is still red hot while the outside is cold if plunged into deep water in the slack tub. When the bit has attained a cherry red color evenly across its width, it is set in about one and a half inches of water, and water from the slack tub is splashed up onto the shank near the bit so that there will be no sharp line of cooling. The bit is allowed to cool in the shallow water without agitation. Apparently, the bit has a great enough bulk so that the interior near the cutting edge cools slowly when it is in shallow water, producing a soft tough steel inside, grading into hard steel on the outside. Since it is not agitated, a curtain of steam is in contact with the bit, producing a cooling rate somewhere between cold water quenching and air cooling. This process produces steel somewhat softer than if cold water quenched, but since only martensite has a different volume than other forms, any stresses set up are in only the skin-deep layer of brittle martensite on the outside. The churn drill bit may also be tempered as are other tools, that is, by observing tempering colors, but must not be plunged over about two inches deep.

USE OF THE PAN AND THE ROCKER

The Pan

The gold pan, one of the most useful tools in prospecting, is used to concentrate materials

on the basis of specific gravity. Its greatest use is in determining whether gold or platinum is contained in gravel, but it is also useful for determining which, if any, other heavy minerals are present and what types of rock pebbles are contained in the gravel. It is also used to separate gold or amalgam from other minerals after a cleanup and to determine the amount of free gold in crushed quartz.

In the section on prospecting and exploration, several operations were discussed in which the pan was used and before describing the technique of panning, it may be helpful to list some of them again: determining the amount of gold in any "panfull" of gravel from a shaft, determining whether any gold exists in the bed of a stream, determining the distribution and limits of pay in an open cut, determining the concentration of minerals on the surface at different points along a creek or a hillside in order to find a lode farther up, separating gold and amalgam from placer concentrates, panning crushed quartz, removing fine material from gravel so that the rock particles may be identified, and determining amounts of heavy minerals in drill hole samples.

Pans are usually 16 inches or 12 inches in diameter although some even smaller are made. A new pan is coated with grease and it should be heated to burn off this grease, and to produce a dark color against which metallic colors can be readily seen. Pans should not be allowed to become rusty but should be turned over when not in use.

In panning, the prospector first fills the pan with dirt, gravel, crushed quartz, or whatever is to be sampled, and submerges it in water, in a tub or pool. The material is then loosened and dug up with the fingers to break up any sticky sediment. From this point on, different panners use different techniques, but they all achieve one fundamental result. They make sure the heavy minerals have settled beneath the surface of the material; then they remove the light upper materials. To do this, the pan, with its watersaturated load, is vigorously moved in a horizontal plane either with a sideways shaking, a quick circular motion, or a combination of both. This movement is quick enough so that the whole gravel mass is agitated and the heavy minerals are allowed to settle. The pan is then tilted forward slightly and the lip of the pan held beneath the water. A gentle motion is used to move the pan forward to allow the water to flow over the surface of the gravel, after which the pan is lifted enough to let the water wash away with the fine material from the top. This movement is repeated several times, sometimes with a sideways "wobble" to make the water swirl and remove slightly heavier particles, but it must always be gentle enough so that the mass of gravel does not move. After a few swirls, the pan is agitated again to insure that the heavy minerals will always be beneath the surface of the gravel. As the coarse pebbles show up at the top, they are skimmed back with the fingers and discarded. Enough water should be present to make sure that these pebbles are cleaned of any gold particles before being raked over the edge.

The cycle of agitating, washing, and skimming pebbles is repeated until only a small amount of fine material is left. Of course, as the material becomes more concentrated, the movements become less vigorous, and more care is exercised in the whole process.

When only one or two tablespoons of material are left, a little clean water is introduced and gently swirled around the circumference of the bottom. The light material is washed around the edge, leaving a "tail" of heavier minerals. If it is desired to save the gold or other heavy mineral, the panning may be continued carefully until all the unwanted material is gone, or the gold may be scraped out with a finger after the light material has been swept to the back of the pan.

The tablespoonful of material which is left after the rough panning is called concentrate. An examination of this discloses, besides any gold present, the other minerals in the concentrate. If of predominantly black minerals--magnetite, rutile, hematite, cassiterite, etc.--the concentrate is called black sand. If of garnets, which impart a red color to the concentrate, it is called ruby sand, although this term is less common.

The Rocker

The rocker, a much less versatile tool than the pan, is used almost exclusively for testing placer gravel or for cleaning concentrates; and in the early days of many placer camps, when high grade virgin ground was available, it was also used as a recovery plant for small scale mining operations.

Whereas the pan is used to wash small amounts of gravel (about 1/10 to 1/7 cu. foot per pan), the rocker is used when larger amounts must be washed, as when the material from a shaft is being tested. The rocker is set up near the gravel and water brought to it; or it is set up near water, and the gravel brought to it. Planks are set under the rockers so that the proper grade, from two to four inches, is obtained. The hopper is filled about 3/4 full of gravel and water is poured over it with a dipper while a jerky rocking motion is imparted to the rocker. When all the fines have gone through the screen, the rejects are examined for clay balls, and for nuggets, if coarse gold is expected. The gravel is then thrown away, and the process is repeated. If concentrates are being rocked, and the tailing is to be saved for future cyanidation the rocker is set so that it discharges into a tub.

At the end of the run, the apron is removed and washed into a pan; the riffles are removed, and the rocker cleaned up. The concentrates are amalgamated or panned. Mercury may be used in the rocker if desired.

HANDLING GOLD

Clean-up Procedure

When the time comes to clean up and the gravel is stopped, the flow of water is reduced for a few minutes to allow excess sand and gravel to clear from the riffles. The water is then stopped completely, and the riffles of the first box are lifted, washed off in the box, and set aside. At this point the first box may be cleaned up, or the riffles may be removed from as many boxes as desired. If the first box is cleaned up separately, successive boxes are cleaned up in order; if all the riffles are removed at the start, the entire box is cleaned at once. A riffle section is left in place at the lower end of the sluice to keep gold from washing out to the tailing, or a riffle section is left in the sluice every two box lengths and the sluice cleaned up in sections. A tub may be placed to catch discharge from the tail box if it is desired to save the concentrates.

The contents of the section of sluice being cleaned up are shoveled to the head of the section and the streaming down operation begun. In streaming down, just enough water is allowed to flow through the sluice to carry away the concentrates while the gold or amalgam remains behind. The water should be directed in such a way that the material streams down across the full width of the sluice. The material is kept loose and agitated by pushing upstream with a clean-up paddle, which insures that the water will reach all the concentrates. (See Fig. 16-9). The concentrates at the lower end of the section are worked back and forth with a paddle so that they will remain loose and not become packed. As long as the concentrates are loose, any gold coming down can settle and not be carried over to the tailing.

As the light sands are carried away, the gold and amalgam appear behind the heavy black sands. The usual procedure is to sweep this gold together with a whisk broom and pick it up with a scoop. The heavy black sands are then scooped up for further treatment. After the whole sluice has been cleaned up, it is swept with a broom, and all cracks and corners are brushed and scraped to recover any gold lodged there. If cocoa matting or other fabric has been used, it is washed by agitating it in water in a tub, and the contents of the tub saved and rocked or panned.

RECOVERING GOLD; TREATMENT OF AMALGAM

If the cleanup is in the form of free gold (no mercury has been used), it is first screened to separate the coarse gold from the dust. From the coarse gold the magnetic material (magnetite and tramp iron) is removed with a magnet, and the non-magnetic impurities are picked out by hand. The dust is cleaned by dry panning and blowing in a gold pan. Gold is transported in leather or buckskin pokes.

If mercury has been used in the sluice, the cleanup is in the form of amalgam and is separated from the concentrate by panning in an ordinary pan or in a copper bottomed pan coated with mercury. Sometimes the amalgam is separated from the sands by putting the cleanup in a pail of mercury. The amalgam sinks; the sands float.

The cleaned amalgam is placed on a chamois skin or cloth, the corners of which are folded up to make a sack which is twisted to squeeze out as much mercury as possible, the remaining mercury being driven off by heat. If only a very small amount is involved, it may be heated in an open pan or dissolved in dilute nitric acid. (Vaporizing mercury is extremely dangerous as the mercury fumes are poisonous. Mercury must be vaporized outdoors). Usually, however, enough mercury is involved so that it pays to retort the amalgam. (Mercury is expensive). The inside of the retort is lined with chalk or a paste of finely ground fire clay. The amalgam is wrapped in paper and placed in the retort pot, not more than two-thirds full, and the lid clamped on. This lid is sealed with an asbestos gasket and the same paste as was used to line the pot. A dampened cloth is wrapped around the end of the condenser pipe so that mercury issuing from the pipe rolls down inside the cloth and into a bucket of water. The water in the bucket should never be allowed to rise high enough to cover the end of the pipe, because if the temperature

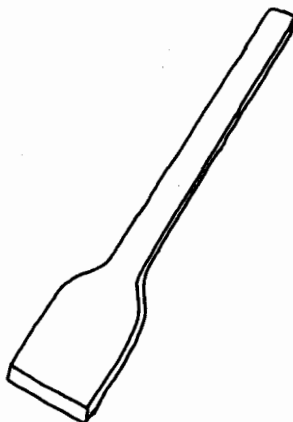


Fig. 16-9. - Clean-Up Paddle

drops, the water might be drawn in and cause an explosion. For the same reason, the condenser pipe must be kept free of obstructions. Some miners allow the end of the pipe to dip into the water, but to such a shallow depth that if any is drawn back, the water drops and the suction is broken before the water reaches the hot retort. If the condensing pipe is water jacketed, the cooling water is turned on; if not, wet sacks are wrapped around the condenser pipe, and the retort is heated until mercury begins to issue from the pipe. The temperature is held constant until distillation stops, then raised until the retort is a dull red and kept constant for about a half hour to drive off the last remaining mercury. For a small retort, the whole process takes about three hours. When opening a retort, the prospector should be careful not to breathe any fumes.

The concentrates from which the gold or amalgam has been separated is treated in a small ball mill, amalgamation barrel or small cement mixer. Of course, if these are lacking, small amounts may be worked by hand in a pan or bucket. Balls or pebbles are placed in the barrel with the concentrate and mercury, and water is added. A small amount of sodium cyanide or lye is added to clean the gold and to promote amalgamation. The amalgamation barrel or ball mill is allowed to run, grinding and scouring the concentrate. After grinding and scouring, the concentrate is removed and the amalgam is separated by one of the methods already described, or on an amalgamation plate set at a grade of about two inches per foot. The amalgam is treated as previously described. If the rejected sands still contain sufficient gold, they may be allowed to accumulate for eventual shipment to a smelter.

Treatment of Mercury

When used in sluices, mercury is introduced carefully into the upper portions so that it does not splatter and divide into small particles which will neither amalgamate gold nor reunite. Such division is called *flouring*.

After long use, and especially if the mercury comes in contact with oil, acid water, talcy minerals, or certain sulfides such as pyrite, arsenopyrite, etc., it may become *sickened*. Sickened mercury will not amalgamate properly and must be cleaned. There are a number of ways to do this. Stirring with weak acid or lye revives mercury to some extent; the addition of a small amount of sodium amalgam is more effective. Sodium amalgam is made by adding about three parts of metallic sodium to about 97 parts of clean mercury. Sodium amalgam is stored under kerosene. Retorting also revives sick mercury and may have to be resorted to if all else fails.

Amalgamating Plates

Amalgamation plates are made of sheet copper; most plates are silver plated before amalgamating. In the absence of silvered plate, the following procedure is used. The copper plate is scoured with sand, then washed with a strong solution of sodium carbonate. It is then rubbed with a rag dipped in a one percent solution of sodium cyanide and flushed clean. A mixture of fine sand, sal ammoniac, and mercury is then brushed onto the plate with a whisk broom until the whole plate is coated with mercury. Mercury is then squeezed through a cloth onto the plate and rubbed in with a piece of rubber or a cloth soaked in a one half percent solution of sodium cyanide. It is then washed off. The original coating may be of silver amalgam rather than mercury. Silver amalgam is made by adding a ten percent solution of silver nitrate or silver foil to mercury. In all of these operations, it must be remembered that sodium cyanide is a deadly poison. It must never be allowed to come in contact with acid or gases which will be generated which cause instant death.

Another way to amalgamate a plate is to first clean it with sal ammoniac and water, lye and water, or dilute nitric acid. (Acid must be completely rinsed off before amalgamation). Mercury is then squeezed on and rubbed over the plate with a perfectly clean cloth or rubber. More mercury is added and brushed crosswise to make slight ridges to help catch gold, silver, or platinum.

Small amounts of mercury, nitric acid, sal ammoniac, sodium carbonate, sodium cyanide (a deadly poison), and sample bottles can be obtained from drug stores. Larger amounts can be ordered from mine and mill supply houses.

Weighing Gold

Nothing has been said about weighing of gold. Large samples, such as those obtained from shafts or open cuts, are weighed in the *tray system*; ounces, pennyweights, and grains. Small balances for this purpose can be purchased second hand in almost any placer camp in Alaska. Very small samples from drill holes are weighed in milligrams. Gold of average fineness has a value of about 10 milligrams to the cent; consequently, when gold is weighed in milligrams, the approximate value in cents is obtained directly by multiplying by one tenth. Assay balances are at times used for this purpose, but more convenient are the portable ones sold by placer drill firms especially for handling small gold samples. (Note that with the advanced price for gold, these values should be adjusted about 20% upward).

HOW TO BUILD VARIOUS APPLIANCES USED IN PROSPECTING

Windlass

Timbers, hewed or sawn about four inches thick and five feet long, are laid down, and into the center of each a three and a half foot hewed pole or timber is mortised. The five foot timber is mortised. The five foot timber is the horizontal base, and the three and a half foot timber is the vertical upright. The upright is braced to the base with a short diagonal stick from each side. These assemblies are fastened together with five and a half foot boards or poles, about four or five on each end of the base and one or two near the top of the uprights. A vertical slot is now cut in each of the uprights so that an axle can be laid across and fitted into the slots.

The windlass drum is a round five or six inch pole with absolutely no taper, cut to length to fit between the uprights. If steel axles are available, they are fastened to the drum as follows: The axle is a piece of $3/4$ or one inch round steel, about one foot long. A hole the same size as the axle is drilled into the center of each end of the drum, the axle driven in, and a small cross hole is drilled through the drum in line with a small hole in the axle. A pin is driven through the drum and axle to keep the axle securely keyed to the drum. A flat piece of steel is welded to the end of the axle, to which a crank can be bolted so that the drum can be turned. Steel rings are fitted around each end of the drum to keep the drum from splitting. The crank is a two by four timber about three to three and a half feet long. The crank handle consists of an 18 inch bolt over which is slipped a piece of pipe. If steel axles are unavailable, the drum is worked down at each end and wooden axles about two inches in diameter are left projecting at each end. One of these is squared on the end so that it can be mortised into the crank. The slot bearings of the windlass, in which the drum turns, are greased or lined with greased leather or bacon rind. If available, ball bearings may be used.

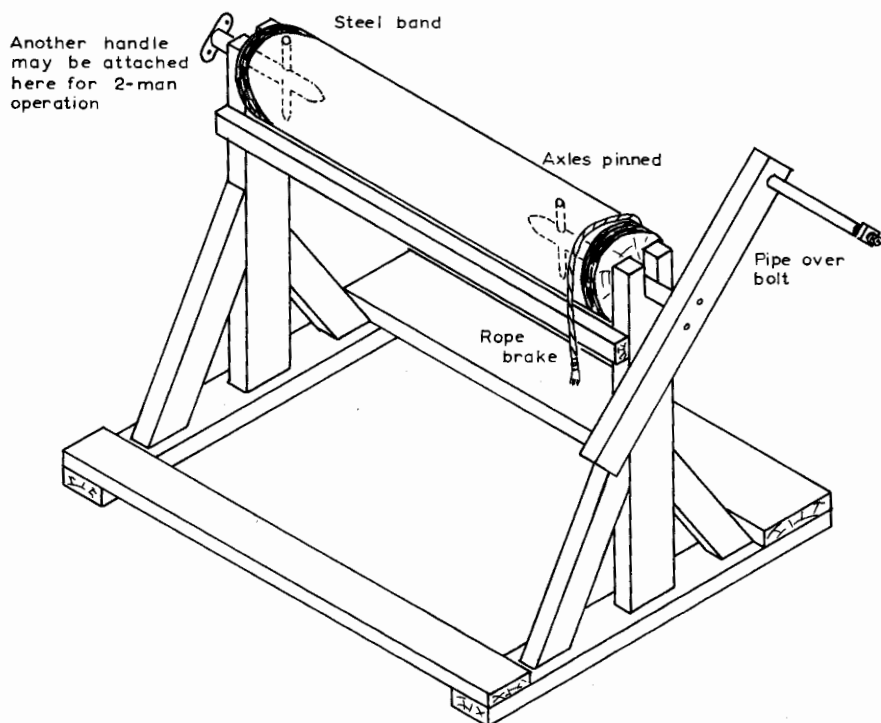


Fig. 16-10 - Windlass Built of Lumber. See Fig. 13-7 for windlass built of poles.

To the drum either a 1/4 inch cable or a 3/4 inch rope is fastened by two or three staples or bent nails. As the drum is turned, the rope travels across the drum; since the rope must be kept in the central part of the shaft to prevent the bucket from bumping and spilling, pins must be driven into the drum at either end to start the rope winding back on itself. For digging a shallow hole which does not require much rope, this precaution is not necessary. The 1/4 inch cable is more satisfactory than the rope because more length can be wound in a shorter distance on the drum.

Near the top of the uprights, about on a level with the drum, one or two crosspieces are nailed. A rope is tied from the cross piece and draped over the drum, and by pulling down on this rope, the windlass man can brake the fall of the bucket when lowering it empty.

Some windlasses are equipped at the level of the base with a board pivoted at one end so that it can be picked under the bucket when it reaches the top. Fig. 16-10 shows a windlass.

Rocker

A rocker consists of a bottom, two sides, riffles, apron, hopper, rockers, and handle. No special problems are encountered in the construction, except perhaps that boards wide enough for the bottom may not be available, and it may be necessary to line the rocker with canvas. For racking the gravel from drill holes where small amounts of gold are involved, a rocker with an unlined, smooth, one-piece bottom is best. Three-fourths inch lumber is used. Fig. 16-11 shows one type of rocker.

SLUICE BOXES AND RIFFLES

If used in prospecting at all, sluice boxes are usually small wooden boxes. The construction of large steel boxes used in large scale mining is not considered here.

Most boxes are twelve feet long, although limitations imposed by transportation methods sometimes makes necessary the use of ten or even eight foot boxes. Sluice boxes may be of two types: butting or telescoping. Most boxes for prospecting are twelve inches wide, with

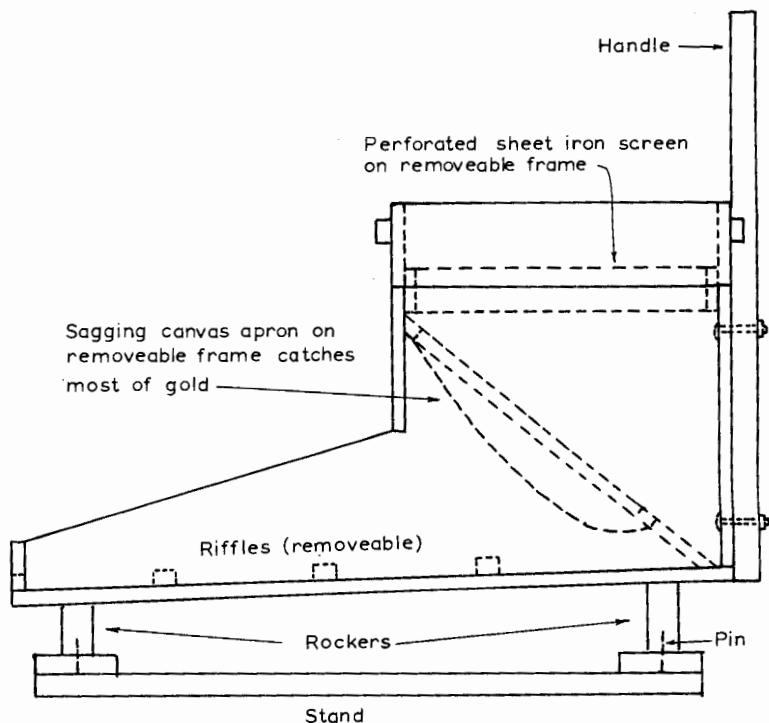


Fig. 16-11 - Rocker. 1" stock, 3'-4' long, 1 1/2'-2' wide. Much latitude in design and construction, so long as principles are embodied.

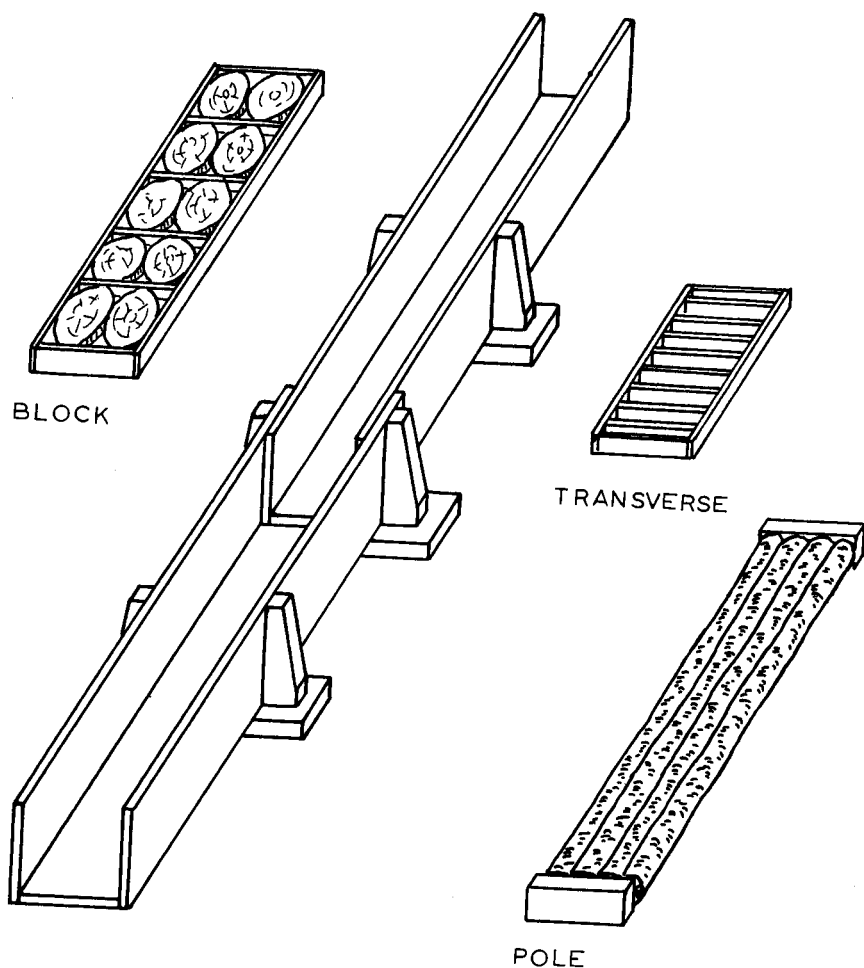


Fig. 16-12 - Telescoping Sluice Boxes and Riffles.

sides twelve inches high. The bottom should be of full one inch material; the sides may be $\frac{3}{4}$ inch thick. Such boxes can be handled easily by one man; they require relatively little water, being narrow, and they will handle all the gravel one or two men can shovel in.

Native spruce lumber produced in Interior Alaska excels imported lumber for the manufacture of sluice boxes, in that it is tough and wears better. The construction of sluice boxes is simple. The boards are cut with square ends, twelve feet long, and the sides nailed to the bottom. Two 2×6 or 4×4 inch sills are cut twelve to twenty four inches longer than the width of the box, and side braces are fastened to the sills by mortising. One of the sills goes in the center of the box, and one at the upper end. If butting boxes are used, the sill with its braces, which goes at the upper end of the box should be so located that the lower end of the next box upstream is supported on the same sill. If telescoping boxes are built, this feature is not necessary, but the bottom boards must be tapered so that the lower end of each box slides into the upper end of the next for about four inches.

For small hand operations the telescoping boxes probably are more convenient. No trouble is experienced in making the joints between boxes water-tight, and the string of boxes, or the sluice, can be made to curve slightly if necessary.

Riffles for small shovel-in sluice boxes are usually fairly simple. The most common are pole riffles. Poles two to four inches in diameter are cut four feet or six feet long. They are laid side by side until they have a width equal to that of the sluice box. A board is nailed across each end, tying them together. Pole riffles are laid in the sluice longitudinally end to end. They are held in place by nails driven part way through the side boards.

Transverse, or hungarian, riffles lie at right angles to the length of the sluice. Although many types are used in mining, for hand shoveling operations simple riffles made of two by two inch stock separated by a space of about two inches are most common. The riffles are made up in sections about four inches long with one by two inch sides.

Block riffles are made of sections of tree trunks about two to four inches thick. These provide a vertical grain surface which wears well. The blocks are trimmed to size and supported between side boards with a two inch space between blocks.

Riffles mentioned above and a sluice box are illustrated in Fig. 16-12.

References

Surveying and Mapping

Lahee, Frederic H., 1941, *Field Geology*, 4th Ed.: McGraw-Hill Book Co., Inc., New York
 Peele, Robert, 1941, *Mining Engineers' Handbook*, 3rd Ed.: John Wiley and Sons, Inc., New York

Drilling Rock for Blasting, Use of Explosives

duPont Co., Inc., 1960, *Blasters' Handbook*, 12th Ed.: Wilmington, Delaware
 Peele, Robert, 1941, *Mining Engineers' Handbook*, 3rd Ed.: John Wiley and Sons, Inc., New York

Blacksmithing

Drew, James M., 1943, *Blacksmithing*: Webb Book Publishing Co., St. Paul, Minnesota
 Stoughton, Bradley, Butts, Allison, and Bounds, Ardney M., 1953, *Engineering Metallurgy*: McGraw-Hill Book Co., Inc., New York

Handling Gold

Boericke, William F., 1947, *Prospecting and Operating Small Gold Placers*: John Wiley and Sons, Inc., New York
 Peele, Robert, 1941, *Mining Engineers' Handbook*, 3rd Ed.: John Wiley and Sons, Inc., New York
 Savage, Eros M., 1934, *Prospecting for Gold and Silver*: McGraw-Hill Book Co., Inc., New York
 von Bernewitz, M. W., 1943, *Handbook for Prospectors and Operators of Small Mines*: McGraw-Hill Book Co., Inc., New York

Chapter 17

TRANSPORTATION; CLOTHING; SHELTER; FOOD; TECHNIQUES AND EQUIPMENT USED IN CAMP LIFE

These important items vary with the time of year and the locality in Alaska. In general, Alaska possesses only three localities sufficiently different from one another to require widely different techniques: Southeastern Alaska; Interior and Gulf Coast Alaska; and the Northern and Bering Sea areas, where no timber is to be found and severe Arctic conditions are encountered. High mountains in any of these localities may require that certain specialized techniques be used, such as the proper method of traveling on glaciers.

TRANSPORTATION

The prospector of today has at his disposal many more types of transportation than did the prospector of thirty years ago. A framework of roads serves many districts, and the airplane has largely eliminated overland dog team travel, although dogs may still play a part in moving the prospector's outfit.

Southeastern Alaska

In Southeastern Alaska, and in fact along the entire coast, boats may be used in transporting supplies to the point upon the coast nearest the prospect. For reconnaissance, a larger boat is used to serve as a base camp while trips are made on foot into the surrounding hills. Inasmuch as boating anywhere requires a considerable amount of skill, it should not be attempted along the Alaskan Coast without adequate previous experience. The Bering Sea and Arctic Coast especially are dangerous as many shoals and very few harbors exist.

In Southeastern Alaska, rivers and fiords make it possible to penetrate inland in many places. If an area relatively far removed from the coast is to be prospected, the boat is taken as close to the area as possible and supplies are packed inland. Thick, wet vegetation and mountainous terrain hinder hiking. There are practically no pack horses in Southeastern Alaska, but a good mule might be used to advantage there. For a short time in the northern part of the region, dogs could be used to haul supplies from the coast to an inland base camp. It is customary to fly supplies for inland points to a lake if one can be found which is closer to the prospect than the sea.

Interior

There is no one best method of transportation in the Interior of Alaska. The relative merits of the several different types must be weighed for each locality, and the most economical of time and money chosen. Today most prospector's outfits are transported by air, the supplies being flown from some point on the road to a lake or landing field closer to the prospecting area. The time saved more than makes up for the cheaper cost per day of water or dog team transport. Where a road or railroad runs close to an area being prospected, of course, supplies are hauled by truck to the point nearest the prospect.

It may also be possible to take a boat to within a short distance of the prospecting area. Interior Alaska rivers, in general, are too swift for canoes, although the native "ratting canoe", a kind of open kayak, is used to some extent on some of the streams. The traveler sits in the bottom and paddles or pushes himself along with two sticks. At best the ratting canoe can carry only a small pack in addition to the paddler. The poling boat, a more practical means of water transportation, is from 16 to 30 feet long. It has flaring sides and turned up bow so that it can jut well up onto the bank, an advantage along muddy cutbanks. Formerly it was poled, but now it is propelled by an outboard motor, which may be hung on a lift, a device for raising the motor when a riffle is reached. At such places the boat may be poled, winched, or lined up. Lining is done by pulling on two ropes, one attached to the bow and the other to the stern. This arrangement allows the boat to be kept in the current rather than being pulled into the bank. If two men are together, one can line and the other pole.

In the overwhelming majority of districts, however, the supplies are transported farther by air and landed on a lake or improvised airstrip near the prospect. Pilots have no hesitation about landing on lake ice covered by snow if they know that hard drifts have not formed or that water does not underly it, but they will not and should not land on a bar or flat until someone on the ground has examined the site. Whoever marks out a field and certifies it as being safe for land-

ing should be a person of experience and judgment, for loss of property and possibly of life are the price of poor judgment. Several points should be kept in mind concerning such a field. First, the field must be long enough for the plane to land on and take off from. Next, the approaches must be unobstructed and the field must not be so located, as in a valley near a tributary, that there are frequent gusts across the field. A grade in one direction is permissible, and rolls several hundred feet apart are acceptable, but short rolls, bumps, or drifts are not. Some pilots will land on a field with only one unobstructed approach, but such fields are dangerous and should be avoided if possible. The strip should be snowshoed about 15 feet wide and marked with spruce limbs two to three feet high every hundred yards along each side. Any person marking out a field should be willing to be a passenger on the first landing. Fig. 17-1 shows an airstrip being snowshoed.

Before choosing a method of air transport, the prospector should investigate to see which airline serves the area in which he is interested. Usually the company holding the mail contract into an area can supply the cheapest transportation. Such a company makes regular flights and has an established fare and freight tariff. In general, chartering an airplane creates a rate per pound which is higher than that regularly established. The larger airplanes, DC-3's and C-46's, of course provide much cheaper transportation, but they require long airstrips and a relatively large amount of freight. (About 6000 and 12,000 pounds respectively).

Even if a small plane must be chartered, by flying with the airline which regularly serves a region, charter time can be kept to a minimum. The point nearest the prospect is reached by a regularly scheduled flight, and a short charter flight from there can be made.

An even cheaper means of air transport is by taking advantage of parcel post to points which have post offices or mail drops. Many items can be sent parcel post, at a rate of from $1/3$ to $1/2$ the air freight rate. Before the final plans are made for the air transport of supplies, therefore, the prospector should determine where the post office nearest the prospect is located and the parcel post zone. After determining rates, the prospector should discuss his freight problem with the airline serving his area and make a careful comparison of costs of the different possible routes.



Fig. 17-1 - Snowshoeing an Airstrip

It is with the transport of supplies beyond the last road, air, or water terminal, where the prospector is on his own, that the following is concerned. If miners are operating in the area, a tractor and Go-devil might be rented to haul the outfit to the base of supplies, and for anything more than a few hundred pounds, this method is the most economical. Lacking this, if a summer's outfit is to be moved, the only practical procedure is to land as close to the base of supplies as is possible before the snow goes, usually in March or early April, and to haul with sled and dogs. If dogs are kept in the locality by trappers, it is cheapest to hire a dog team and driver to do the job. Conditions prevalent in Alaska today, however, are such that even this often is impossible, and the prospector must keep his own dogs. For short hauling, keeping many dogs is unjustified; two seems to be the optimum number. By pulling with two dogs, a man can move up to 300 pounds or more, depending upon the trail. The necessity of hauling wood and packing meat at various times almost makes it essential that one or two dogs be kept throughout the year, and many prospectors have found that their companionship alone makes up for their keep. Harnessed dogs can be of great assistance in climbing mountains if a rope attached to their harnesses is wrapped, not tied, around the waist. Experienced sled dogs can pull a man on skis 50 miles a day, and they help immeasurably if one is on snowshoes in deep new snow. The tow rope can be put to other uses such as parbuckling logs in cabin building.

The freighting should be done during the spring, after it is light and warm but before it has begun to thaw. This time will vary, but from the middle of March to the middle of April is generally safe. If the freighting is put off too long, the sun will thaw around tufts of grass and niggerheads, making bare spots in the trail, which of course hinder the freighting seriously. Especially to be feared is a light fresh fall of snow late in the season for such a fall seems to accelerate the thawing of the old snow.

The first step in moving from the landing site is to snowshoe a trail, choosing the easiest grade available. Where steep pitches are encountered, a switchback is laid out. Sidehill stretches are avoided when possible, and where they cannot be avoided, the snow is stamped down to make a level trail. Where the wind has crusted the snow on a sidehill, it may be necessary to shovel out a level trail, but this usually need not be done for any great distance. In windy country, the trail must be used soon after it has been broken; otherwise parts of it may be blown in again. Stretches which blow in regularly should be blazed or marked with boughs. The blown-in trail has a good bottom and should be followed when possible. A good dog will follow such a trail, and he should be put in the lead. A little extra work expended on the trail is more than repaid in freight moved. A fresh trail, of course, is soft under foot; but after it has set overnight, it is usually hard enough to hold up a sled.

For such freighting, Yukon sleds are best because they will accommodate longer loads, such as firewood, but basket sleds are often used. Both of these types are illustrated in Fig. 17-2. The load, which consists of from 75 pounds to 250 pounds per dog, usually about 100 pounds, is wrapped in canvas and lashed securely. When a top-heavy load, such as a boiler, is hauled, poles are lashed to the sides so that they extend out behind and can be grasped for steadying the load. Fig. 17-3 shows a boiler ready for hauling.

The dog driver walks on short trail snowshoes between the sled and the dogs, pulling with a neck line and steering with the gee-pole, as shown in Fig. 17-4. For freighting, each dog should have a work harness with work collar, tugs, and singletree. Racing harnesses pull across the neck and cut off the breath; consequently a dog cannot work to maximum efficiency while wearing one. If a large work collar must be used on a small dog, the collar should be reduced in size by wrapping old woolen socks or heavy cloth around it. Materials such as wire, leather thongs, and extra rope for making temporary repairs on the trail should be carried.

Dogs should be provided with houses about three feet long, two feet wide, and two feet high, with a door just large enough for the dog to enter. Poles covered with moss make good houses, and the houses should be floored with hay, which is renewed before it becomes packed and hard. Dogs are fed dried salmon prepared along the rivers for dogfeed, or cooked cereal, with which a liberal amount of "edible dog tallow", scrap meat, or salmon is cooked. When dogs were in much more common use than now, special, inferior grades of cereal could be obtained. This is now impossible, and first grade feed must be used; corn meal and rice are most often used. When game is killed for use by the prospector, every scrap of waste should be saved for the dogs. It is, however, unlawful and wasteful to feed game meat which is fit for human consumption to dogs. Dogs vary as much as do human beings in the amount of food and water necessary for their subsistence. Dogs which eat little proportional to their weight have been called "easy keepers". When working, the average dog eats about 1 1/2 pounds to 2 pounds of salmon, or one pound of corn meal with 1/4 pound of tallow per day. When idle, the amounts may be decreased. When dogs are working, they should be fed and watered after the day's work and watered before starting in the morning. When not working, snow will suffice to quench their thirst, but water should be provided if they will drink it.

During periods of inactivity, the hair between the dogs' pads grows out and should be cut off flush with the pads so that it does not collect balls of snow. If snow balls form in the feet in spite of cutting, the dog should be allowed to clean them out periodically. If the claws grow so

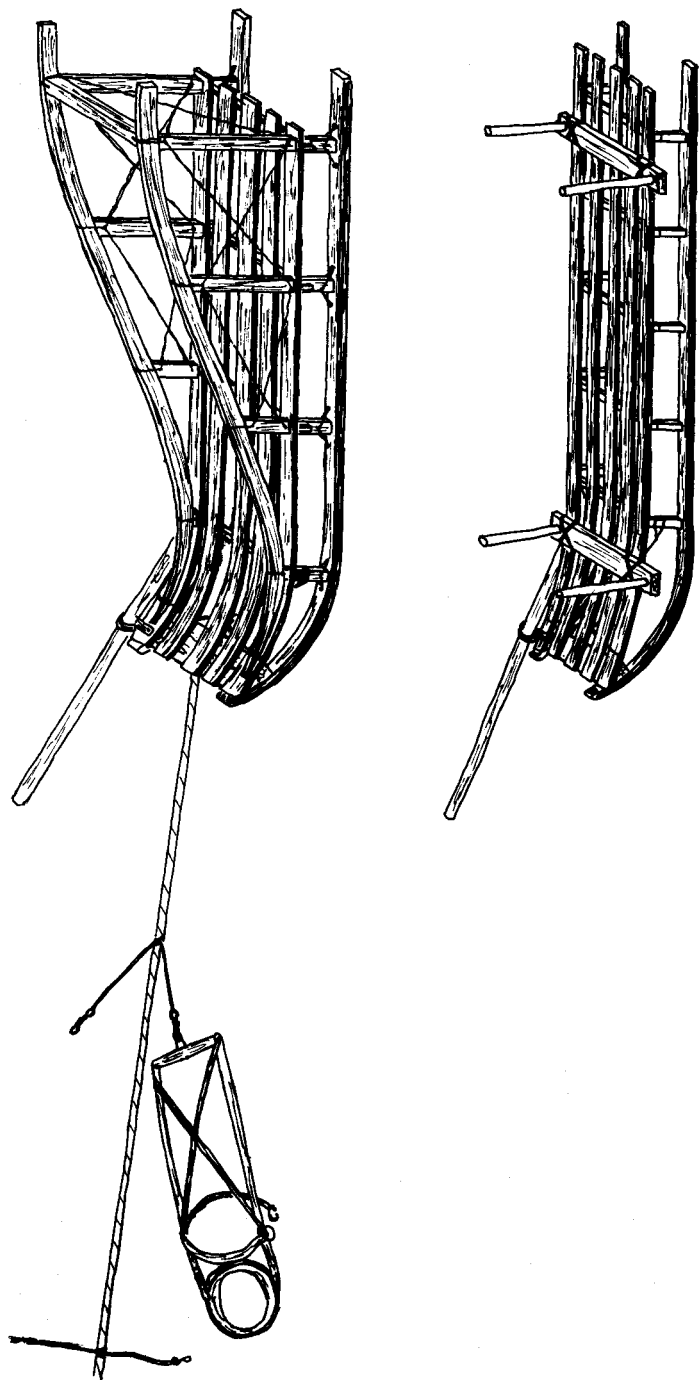


Fig. 17-2 - Basket Sled (top) and Yukon Sled Fitted with Bunks. Harnesses are attached every six feet.



Fig. 17-3 - Doghouse Boiler Ready for Hauling

long that they are in danger of breaking, the ends should be trimmed off with wire cutters by squeezing from the sides (which presents less danger of breaking the claws than if they are cut from top to bottom).

Usually discipline is administered to a shirking dog with a willow switch, which has just as much effect as harsher means. If a fight breaks out in a team, however, the dog driver has no alternative other than to break it up with whatever weapon is near. Men have been seriously bitten attempting to stop dog fights with an inadequate weapon. If a dog is wounded in a fight, and if he can reach the wound with his tongue, ill effects are seldom experienced. If he cannot reach the wound, however, and it shows signs of infection, the hair around the wound should be clipped, and the hole cleaned with a strong boric acid solution which is applied with a cotton swab. The swab is shoved to the bottom of the wound, and worked and twisted until all signs of infection have been wiped away. Iodine is then applied with another swab. This procedure is repeated until the wound is healed.

Certain trail conditions cause dogs' pads to crack and bleed. When such conditions are encountered, the dogs are fitted with moccasins—simple canvas tubes, about 12 inches to 18 inches



Fig. 17-4 - Freighting with Yukon Sled

long, open at both ends, and big enough to slip over the dogs' feet. One end is slipped onto the foot; the other end is folded up and tied in place with string around the leg. When the bottom shows signs of wear, the tube is shifted so that a new area takes the wear.

If dogs should get into an overflow, wetting their feet, they should be driven into dry snow and stopped to give them a chance to lick their paws clean. While the dogs' pads are wet, glare ice must be avoided at all costs because the pads stick to the ice and skin will be pulled off. In very cold weather, the dogs' pads may freeze and crack if they stand around in a packed area. They should be allowed to rest in dog houses with plenty of hay, and their feet should be treated with a mixture of pine tar and olive oil.

If dogs contract worms, several preparations in the form of pills may be administered. Usually these are divided into two categories: those which eliminate tapeworm, and those which eliminate all others. Instructions accompany all such preparations.

A few words should be said on the subject of snowshoes. When the prospector is freighting with dogs or doing any traveling in the winter, his snowshoes are his constant companion. The best snowshoes, it is conceded by all, are the native-made shoes of birch and babiche made of moose or caribou hide. They are light and well balanced; however, they are expensive, costing about \$35.00 at the present time, and are not durable. For this reason, many prospectors use snowshoes built in factories. These shoes have hickory frames and heavy babiche of commercial hides. They are heavy, often poorly balanced, but cheap and durable. Such snowshoes have been released by the armed forces in recent years and can be obtained for \$10.00 or less.

For breaking trail, shoes with a good upturn and enough area to support the body's weight without sinking too deeply are required. The center of balance should be behind the foot so that the front of the shoe will lift easily, even with a small amount of snow on the front of the shoe. The upturn keeps the shoe from digging in under the crust and allows it to glide forward above the snow with each step.

After the trails are well broken, it is sometimes possible to walk on them without snowshoes. More often, however, the trail does not quite support a man without snowshoes, yet does not require full-sized shoes. When the prospector intends only to work on such broken trails, he may use trail shoes, special small ones which will hold him up on a trail or thick crust but not in unbroken snow. Especially when working dogs, are trailers convenient, for the space between the wheel dog and the sled, in which the dog driver walks, is so short that the sled often rides up on long shoes. A type seldom seen in Alaska, but which has been found to make an excellent trailer, is the bear paw, so called because it has no trailing piece but is oval or bear paw shaped. Bear paws provide the same amount of bearing surface without nearly so

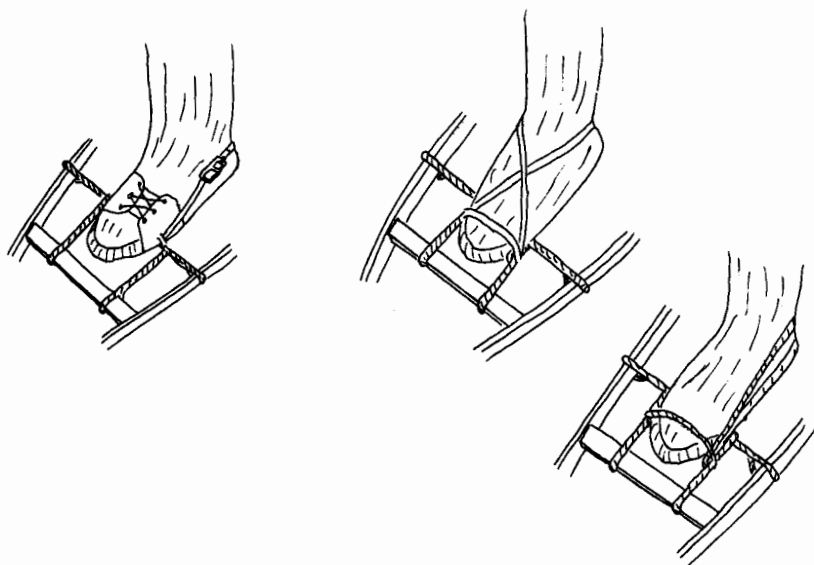


Fig. 17-5. - Three Snowshoe Hitches: Factory Made Sandal (left) and Two Native Hitches.

much length as do conventional shoes. For stepping over the tow line, walking around the sled, and untangling dogs, they provide much greater freedom of motion.

If any amount of snowshoeing is to be done, some type of moccasin or snow boot should be worn. Tight leather shoes, shoe-pacs, or rubber boots chafe the feet; at least long enough to make life on snowshoes miserable for several days. Less trouble also is experienced with the bindings slipping off moccasins than off shoe-pacs.

Factory-built snowshoes often come with leather sandals which are tightened onto the feet with buckles. These are looked upon with disfavor because snow gets between the foot and the leather and eventually turns into balls of ice which cause chafing. Some form of hitch made of canvas webbing, rope, or strings made of twisted cloth is preferred. (Two of these native hitches and one factory made sandal are illustrated in Fig. 17-5).

Snowshoes should not be cached for future use unless the cache will be reached before the next snow falls because the snowshoes will be needed to reach the cache should snow be on the ground. A prospector should never have himself flown to a lake, intending to get snowshoes from a cache several miles distant. A trip of five miles through deep snow without snowshoes can be so exhausting that a man could fall victim to sudden storms or cold weather.

Snowshoes should be treated carefully when in use. The strongest pair may be damaged if they are allowed to bridge so that they hold up the body's full weight unsupported in the middle, or if they are used to walk over snags or stumps. Snowshoes should be varnished in the spring so that the babiche will be well waterproofed for the coming season. To repair the webbing, babiche is soaked until it is soft, then threaded and tied like string; upon drying it becomes stiff and hard.

So far the emphasis has been on winter freighting. How does the prospector transport himself and his supplies through the country in those early stages of the search for ore which in this book have been called "reconnaissance" and "prospecting"? He may have already deposited his supplies at some central point by hauling from a frozen lake with his sled and dogs. From this point he can make short trips in several directions and cover a fairly large area. On the other hand, he may intend to travel through the country, not stopping long at any one place and not returning to his base at all. In this case, hauling a large outfit to a central location before the snow melts is not practical because he can take only what he (and his dogs, if he so chooses) can pack. He will have himself landed at the landing field closest to his point of departure on a lake with a float plane. Here also he should determine his cheapest route by checking with the airline serving his region. The chartering of a plane on floats is relatively more expensive than chartering the same plane on wheels or skis. Not only is the charter price higher, but it flies slower and carries less weight. For this reason a plane on floats should not be chartered to haul freight which could as well have been hauled by a plane on skis earlier.

Anyone intending to travel through the country should carry a map of the area and a compass

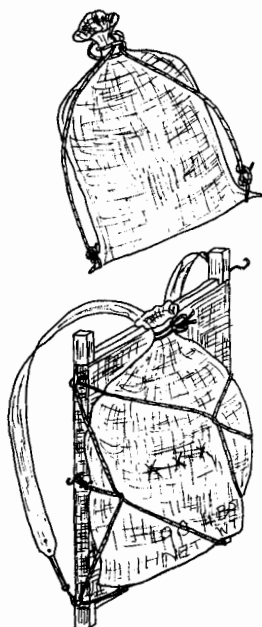


Fig. 17-6. - Packsack Improvised From Gunny Sack (top) and Packboard Showing Diamond Hitch (bottom). Large Hook Sometimes Provide for Carrying Rifle.

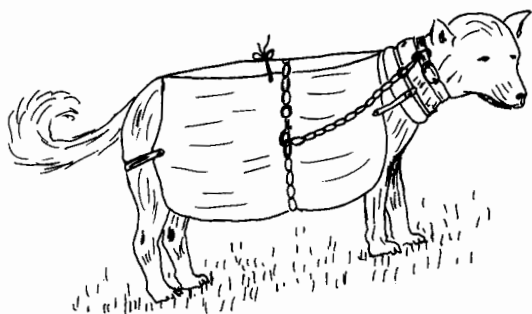
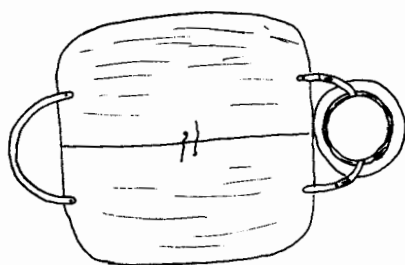


Fig. 17-7. - Dogpack (top) and Arrangement of Pack on Dog. Pack is about 2 1/2 Feet Square (top). Webbing Breast Band may be Used Instead of Work Collar.

and know how to use them. In strange country, the map should be consulted frequently so that the traveler knows exactly where he is at all times. Even in familiar country, open and with good visibility, the compass must be depended upon in snowy or foggy weather. Lacking a compass, the traveler must stop immediately if he loses track of his location in a fog and wait for better visibility. The proper method of using a Brunton compass was described in Chapter 16. Such an elaborate compass is not necessary for finding directions across country, but if a Brunton is owned it may as well be used as a cheaper one. Declination for the area should be ascertained and set off on the compass previous to using it.

After the breakup, heavy articles cannot be moved except by packing, unless a horse and wagon or a tractor is available, unlikely during early stages of prospecting. Most packing is done on "packboards" rather than in pocksacks. The packboard can be used to carry items of peculiar shape and size, whereas the pocksack is limited to small items of regular shape. When small items are carried, they are put into a duffle bag or gunny sack and lashed to the packboard as illustrated. Packboards are manufactured in several sizes and designs. All have a tightly stretched canvas which fits against the back and webbing or leather straps. Some have a special bag which hooks onto the board. For all around work the largest size is best. Some pocksacks are fitted with "tumplines," a strap which can be laid over the forehead so that some weight can be shifted from the shoulders to the neck. Few packboards are so arranged, although there is no reason why they could not be. An improvised pocksack can be made from a gunnysack as shown in Fig. 17-6.

If dogs are to be taken, each should be furnished with a pack. Very large dogs and very small dogs, of course, require different sized packs, but most packs are interchangeable for most dogs. The pack receives very hard usage in brush and should be made of heavy canvas. If a work collar is available, the front end of the pack should be fastened to it, although a strap across the breast is adequate. A strap across the rear, under the tail, keeps the pack from sliding ahead. A dog chain is tied around the pack and snapped onto the dog's collar. Sometimes the two sides of the pack are tied together under the dog. The pack should be connected in some way to the dog's collar because some dogs wander off and lose their packs. If

the pack is fastened securely to his collar and it falls off his back, the dog must either bring it home or bark until he is found. The loss of a pack and its contents on a trip is, at the very least, most inconvenient. Fig. 17-7 shows a dogpack.

Each dog packs from 20 to 40 pounds, or even more if he is exceptionally large and strong. Because packing is hard on a dog, he should not be overloaded; usually 20 pounds is the approximate load carried. Only items which can be wet without being injured should be carried by the dogs. Sometimes a stone is placed in one bag to balance the pack, but it is not often necessary to resort to this ballast. When traveling, the dogs live on dried salmon, supplemented with rabbits, ground squirrels, and other small game which may be legally fed to dogs. Pack dogs exposed to mosquitoes should have mosquito repellent applied to their noses and other affected parts. DDT spray is also effective. Lacking such repellent, they may be plastered with mud. If the dogs are on a chain during mosquito season, they are treated similarly and provided with tight houses with old gunny sacks hung over the doors.

In the early days when foot trails were in common use, the Road Commission maintained cable crossings or "trolleys" over the rivers. Some are still kept up; others are still standing and usable, despite lack of maintenance. Where such crossings exist, the prospector's route should be laid out to take advantage of them. When they are not available, he must ford or raft the streams which bar his path. If the stream is small, he may ford it in his gum boots. If large, he should remove his socks, insoles and pants, and wear his boots or shoe packs to protect his feet. The dogs' packs must be carried over, and the dogs forced to swim on the ends of their chains. If the stream is deep and swift, a stick should be used, against which the prospector can lean, and the pack should be arranged so that it can be thrown off instantly should the current sweep him off his feet. After crossing, the boots are emptied of water, and the wet insoles, socks, and pants replaced.

Deeper rivers must be rafted. A stretch of river is chosen where the current is sluggish and where dead trees are available. If the trees are small, many must be used; if larger, of course, fewer will serve. They are cut about 12-15 feet long, laid side by side, butts at one end and small ends at the other. A small pole is laid across the raft near each end, and the raft logs securely lashed to them. A rough paddle should be hewed from a pole. The packs, or as many of them as can be carried, are tied in the middle, and the raft paddled across. If the dogs will swim, they should be allowed to do so; otherwise they must be tied to the raft. After the crossing, the raft should be disassembled and the logs laid up on a stump or log to keep them off the ground, well above high water, in case the prospector should return that way and need to cross back.

Because such rafts are usually unstable, crossings should not be attempted in fast water. Rafting down fast streams likewise should not be attempted without a large, buoyant, well built raft, fitted with a sweep, and even then, not until a considerable amount of experience has been acquired with an experienced man. Many men have drowned while attempting to raft swift rivers.

Pack horses or mules can be used in Alaska during the summer. Their keep through the winter when they are idle, however, makes their upkeep almost prohibitively costly. In most parts of Alaska, the cost of moving the animal to the starting point is also too great. Horses should not be taken where they cannot forage for themselves. Packing a horse is more difficult than packing a dog, and some instruction is almost essential. The horse packs from 150 to 175 pounds in rough going; a mule of the same weight packs twice as much.

The horse or mule should be shod before starting and fitted with blanket and pack saddle. Extra shoes, hammer, nails, cutters, and rasp should be carried. The first step in packing a horse or mule is to throw on the blanket, then cinch the pack saddle on tight. A pannier is then hung from each side and filled. If commercial panniers are not available, they may be improvised. A gasoline case set in a canvas bag or a stiff rawhide which has been moulded around a gasoline case while wet, allowed to dry, then removed from the form, makes satisfactory panniers. Panniers are hung from the "sawbuck" of the pack saddle. Above each pannier and also on the sawbuck in the center of the animal is loaded the light bulky duffle, and over the load is thrown a tarpaulin. Another cinch is put under the horse, and the lashing rope tied across the load between the ends of the cinch. The load is now lashed on with a diamond hitch.

Mules are conceded to be better all around packers than horses, more intelligent, and less likely to injure themselves through intemperate eating or accident. Their chief drawback is the smallness of their hooves.

At night the pack animal should be picketed or hobbled to keep it from wandering off. Mules and horses may lose their packs as do dogs, so the loads must be securely lashed before starting in the morning.

For extended trips, supplies may be replenished by air drops. This method also may be resorted to for the purpose of cutting down the amount which must be hauled from the nearest landing spot to a main base. However, it is generally unsatisfactory for the following reasons: Fragile items cannot be dropped without a high percentage of loss. At least one man must be on the ground beforehand to spot the items as they drop and to retrieve them immediately.

Where more than one or two items are dropped, one item can become hopelessly lost; untold man-days have been spent searching for lost items. Since the man must be on the ground when the items are dropped, it is necessary to rendezvous at a particular time and place. Airplanes cannot fly in poor weather, and consequently the prospector may be waiting, literally chained to one spot, for several days. When the plane does arrive, often wind conditions keep it several hundred feet off the ground, making the dropping erratic. Another reason for avoiding air drops whenever possible is that they are expensive, since a plane usually must be chartered to drop a hundred pounds or so. Usually an extra person is needed to do the dropping, decreasing the payload which the plane can carry. A final reason is that air dropping is sometimes dangerous.

Items to be dropped should be tied inside of several gunny sacks. Flour or sugar may burst some of the inside sacks, but is usually held by the outer one. Fragile items must be well padded. Packages should have colored streamers attached to them, but the streamer must not be allowed to catch on the plane. Notes are sometimes fastened on the inside of a roll of toilet paper. The unwinding paper leads to the spot where the note lands.

When traveling through the country in the summer, the prospector carries small light tarp, or preferably a light tent. If only a tarp is used, a mosquito bar must be carried. If on a trail, currently or even formerly maintained by the road commission, shelter cabins may be available on every day's journey. In the winter time, these cabins must be reached, or a heavier tent and small stove must be carried. (Types of tents will be described under "Shelter").

If the prospector is traveling light with only a tarp to shelter him, he is said to be *siwash-ing*. In good weather this practice is not uncomfortable, and a small cooking fire may be sufficient. In cold or wet weather, however, he must build a large fire and bank it well before going to bed to dry his clothes and tarp and to keep him warm. Pots are hung from a slanting pole over a small part of the fire when cooking. If it is necessary to make camp just at dusk, the available daylight should be used in gathering dry wood. In wet weather, dry kindling can be made from birch bark or the small dead branches of the bottoms of spruce trees. (It should not need to be emphasized that anyone going into the hills must carry plenty of matches at all times. Matches should be carried in a shirt pocket where they will stay dry. In addition, a full waterproof match box must be carried for emergencies).

It is the custom in most parts of Alaska to use any cabin which is reached in the course of the day's travel. Such cabins must be left in a clean and serviceable condition, with kindling, dry wood, and matches readily available. Before starting a fire in a strange cabin, the prospector should search the stove carefully to make sure that no explosives are cached in the oven for safekeeping.

The foregoing discussion of transportation in the Interior applies also to the Arctic, with more emphasis being placed on windy conditions and careful consideration being given to the changeable weather of the Arctic. Coast traveling is done by skin boat. The Arctic coast is dangerous and is best traveled in the company of Natives who have grown up in the region. It is best under such circumstances to hire a man and his boat for a particular job and to rely upon his judgment for the trip.

COMMUNICATIONS

It might be thought that communication between an isolated prospector's camp and the outside world is almost impossible. However, systems can be worked out to provide at least some contact. In the Interior, the Fairbanks broadcasting stations have programs on which announcements are made in the form of news items. These programs provide a daily, except Sunday, one-way contact to anyone possessing a broadcast receiver within range of the station's output.

If the base camp is on or near a regular mail route on which a small plane is used, it may often be arranged to have the pilot keep an eye on the camp and perhaps even to drop mail. In an emergency, a message can be stamped in the snow or some other signal given. Pilots usually are cooperative in these matters, partly to be helpful, partly because it is good business, and partly because they never know when they may be forced down in the vicinity and the favor be returned. On a larger prospecting project, where several men are working with a drill or have other mechanical equipment in operation, two way radio communication is desirable, because if a breakdown occurs, the machine and crew will be idle until parts arrive. If a radio transmitter is available, much time can be saved.

Necessary radio equipment consists of a communications receiver, a transmitter, and a source of power, which may be a generator or batteries, charger, and vibropack. If the camp is to be deserted during the winter, the best power supply is a generator because heavy batteries, which would have to be taken out to prevent freezing, are not needed. That ordinary 110 volt, A.C. equipment can be used with a generator is an added advantage. Application is made to the F.C.C. for a station construction permit, after which a commercial station license is issued. A restricted radio telephone operator's license permits the prospector to carry on communications after the station is set up but not to make adjustments or repairs. A person possessing a license of the proper grade must install the station, and some provision must be made to check the

frequency periodically. Regular schedules must be kept.

SHELTER

The type of shelter used varies with the season, locality, and type of work. For a summer's prospecting at a fixed point, a fairly large wall tent, from 8' x 10' to 10' x 12', is adequate. Such a tent can be furnished comfortably and serves as a home in fairly cold weather. Tents have been used in extremely cold weather but the experience is not pleasant. A fly over the tent and snow banked against the walls make it warmer.

If the tent is to be used for only a few weeks, it is set up between two inverted V's, each made by lashing two poles together at the height of the ridgepole. The ridgepole is put through the tent so that each end rests on one of the inverted V's. A pole is lashed between the end frames on each side at the level of the eaves to which are tied the eave ropes. Logs are laid around the base of the tent so that the walls can fit tightly against them, yet be kept off the ground to keep the canvas from rotting. A bed may be made of poles covered with spruce boughs or simply by filling a cribbed area with spruce boughs. A roof seam at a convenient place should be slit enough to take a metal stove pipe ring consisting of two parts, one outside and one inside, which are fastened together to support the stove pipe and keep it from burning the tent. Rocks are then arranged to hold the stove off the ground or sticks driven into the ground, and tin cans fastened to their tops.

The usual stove is a variety of the Yukon stove, as any sheet metal, end-stoked wood stove of local manufacture is called. The most popular Yukon stove has a rectangular cross section, 12 inches deep, 18 inches wide, and is about 30 inches long. It has a small oven at the back and takes 5" pipe. Other Yukon stoves may have square sections, round bottoms, no ovens, cast iron tops, etc. The square or rectangular section is preferred if the stove is to be hauled on a sled; the round bottom provides more space for ashes and is preferred once a camp is located permanently. Stoves and pipe rust very quickly if left in an unheated tent or cabin. Rain flowing down the pipe soaks up the ashes, subjecting the stove to continual dampness. In the winter snow may fill the entire stove, to melt in the spring. To obviate this, a bucket or can should be inverted over the top of the pipe when the prospector leaves a cabin or tent for any length of time.

If the tent is to be used for an entire summer, the prospector erects a tent frame. The nominal dimensions of a tent, say 10' x 12', do not take into account the amount of canvas taken up by the seams. About one to two inches is lost at each seam, so a tent nominally 12 feet long, if it has six inch seams, is about 11 1/2 feet long in reality. For this reason the dimensions of the tent must be measured carefully. Logs are laid on the ground in the shape and size of the tent floor, leveled up, and notched together at the corners. Uprights are nailed to these logs at the corners and at regular intervals around the sides. On the sides of the tent, these uprights are as high as the eaves; at the centers of the ends, they are as high as the ridgepole. Horizontal poles are nailed to the uprights to take the ridge and eaves, and rafters nailed between them. All poles which will be in contact with the tent are smoothed. The corners are braced, and braces are also placed elsewhere where needed to stiffen the tent frame. The tent is stretched over the frame and tied down. With such a frame, shelves and tables may be nailed against the walls, and the whole tent made more comfortable and roomy than when not framed.

Tents may be of white, untreated canvas, or of brown canvas, or of some light, silky material; the white tents are lighter inside than the dark colored ones. For sledding, a light canvas tent is desirable; for packing, a very small, light one is necessary. A wall tent, 5' by 7', with 2 foot walls, should not weigh over 5 pounds if it is to be packed. Tents may be treated with an anti-mildew compound to inhibit molding. They may also be waterproofed, but this increases their weight.

For cross-country summer trips, a one-man tent, which need be supported in only one place, is light and easily set up. Any small tent made of light nylon, silk, or like material suffices, and its shape is a matter of personal preference. A light oilskin ground cloth should be carried to floor the tent and can be used to keep the pack dry while traveling.

Tents should be thoroughly dried before being folded and put away; otherwise they will mold and rot.

For a winter's prospecting, it is best to build a cabin. A prospector's cabin should be small; 10' x 10' is ample for one man; slightly larger than that for two. A small cabin is less expensive to build, in time and material, and easier to heat. A level spot, near water and in no danger of flooding, should be picked for the site. The bottom log may be set in the dirt or on rocks or short sections of tree trunk. Sphagnum moss is cut with a mattock and packed to the cabin site. (A sluice fork is handy for packing moss). The bottom round of logs is laid out so that logs on opposite sides of the cabin have their butts facing in opposite directions. As each round is laid up, the logs in any one wall have butts at opposite ends, although if taperless logs are obtainable, this is not necessary. Each log is notched to fit over the rounded log beneath. The moss is laid as the logs are added or the cabin erected and mossed later. The corners,

however, must be mossed as it goes up because there is no way to get the moss between them later. The openings for doors and windows may be left as the cabin is built or cut later. If left during building, the logs are butted into a two inch board. On larger cabins, the logs are pinned together with wooden pins. (The pin is left loose so that the logs can settle upon drying). The smaller cabins do not require pinning.

On the ends of the cabin, the walls are built up to peaks, upper surfaces of the peaks are smoothed off with an axe, and swaybraces are run from the peaks to the side walls. A ridgepole and two side purlins are set into mossed notches in the ends of the cabin. Small round poles or larger split poles are laid from the ridgepole to the eaves, extending out about 1 1/2 feet. Poles are laid at the eaves and up the peaks to form a shallow box on the roof, into which moss is laid and dirt piled over the moss until the roof is six inches to a foot thick. Such a roof, which is relatively waterproof and very warm, must be flat so that the dirt does not slide off. Sheet iron, if available, is used to cover the dirt; boards are sometimes used but are a fire hazard.

A five gallon can with a hole in each end serves as a safety flue. The window can be made of flexible plastic, of which there are several varieties on the market. Strips of fur or canvas are nailed around the door jamb to seal out air. Dirt is piled up around the cabin, and in winter, snow is piled up to the eaves. In Southeastern Alaska, a cabin as just described serves satisfactorily, but a sheet iron or shingle roof should cover the sod or dirt.

Where timber is scarce and small, an "igloo" may be built. Four posts are set at the corners and caps placed across them to form a rectangular frame. Poles are leaned against the caps at a small angle from the vertical until the area is entirely enclosed, save for a door. The roof is covered with poles, moss, and dirt, and sod and moss built up around the walls. The slight inward lean keeps the moss and sod from falling over. Such a shelter is satisfactory during the winter but is damp and generally not a good habitation in the summer.

The cabin obviously cannot accommodate a season's supplies, so a cache must be constructed. If the prospector intends to be at camp during his entire stay, the cache may be no more than a platform of poles on which the supplies may be placed and covered with a tarp. (Nothing should be laid on the ground in the summer time without placing sticks or brush under it). Usually, however, the time comes when the camp is to be left for some period of time, and a safe cache is necessary. Three or four trees are cut off about 8 - 10 feet high. If the trees are not situated properly, posts are erected and braced. On the posts is built a platform of poles which overhangs all around. This overhang keeps out climbing black bears and the height alone is enough to keep out grizzlies and brown bears as well as wolves, coyotes, foxes, and ground squirrels. On this platform the supplies may be piled and covered with a tarp, which must be lashed down if it is to be left. Dried groceries should not be near the top as they will get damp. Tools, pots, pans, etc., should be at the top, or spruce boughs placed there to keep the tarp away from the groceries. Fig. 17-8 shows a simple cache.

Such a cache is unsatisfactory in many ways; a better one consists of low walls and a tent frame above the platform. Even better is a small log structure above the platform with a door which can be locked. A ladder which can be taken down is used to reach the cache.

Tree squirrels and weasels present the worst danger to cached groceries. To prevent their entrance, smooth sheet iron is nailed around each upright, and sometimes large five gallon cans are inverted over each post before the platform is put on. All trees around the cache are cut down. Even so, tree squirrels, if they are numerous, usually get in. If the prospector is around camp, he can trap or shoot the squirrels, but the only sure way to combat tree squirrels is to place the groceries in cans or steel drums located in the cache. The tops of the drums are cut half way around, and the tops bent back. After they are filled, the tops are bent down and wired shut. A hole is punched in the bottom in case water gets into the drum. All this is inconvenient and takes time, but it is the only way to store food so that it will be perfectly safe from all types of animals. An instance is known of prospectors who left groceries in barrels with their tops cabled shut. It was above timberline where no tree squirrels lived, and in a five foot high cache, into which ground squirrels couldn't climb. However, a grizzly bear climbed into the cache and although he could not open the barrel, he pried the tops back enough to admit the ground squirrels, then rolled the barrels onto the ground. All the dried food was eaten by squirrels. In this case the prospector believed that the food was safe but they had not foreseen the bears and squirrels working together.

When leaving a cache or cabin, some prospectors string tin cans, dish pans, etc., on wires across the doors. Others put up a wind sock on the cabin, which creaks in the wind. These devices are supposed to make enough noise to frighten away bears. Neither of these is effective against a determined bear. Old cross cut saw blades set on edge on the window and door sills and on the platform of caches sometimes are effective. Nailing the sheet from flattened barrels over the windows and doors usually keeps bears out of the cabin, but a determined bear can pull off such devices easily. Set guns, poison, and baited cod hooks are cruel, dangerous, and illegal and should never be used. However, when approaching a strange cabin, the traveler must be on the lookout for such traps as well as for the conventional bear traps.

Fuel almost invariably consists of wood. Wood is cut in the spring or summer and allowed to dry until fall. The only two trees commonly used in the Interior for fuel are spruce (white and



Fig. 17-8. - Simple Cache and Tent

black) and birch, although a limited amount of tamarack is also cut. In Southeastern Alaska pine and hemlock are available also. Spruce trees are cut and a strip of bark removed for the full length on either side. The limbs between these strips may be left until later, as the ones underneath tend to hold the trunk off the ground to speed the drying. In the fall the limbs are removed and the trunks bucked into uniform lengths, sixteen feet long if the wood is to be hauled with horses or tractor, shorter if only dogs are available. If the wood is not to be used until the following year, it may be stacked pyramid fashion without being bucked into short lengths, to keep all but one end off the ground.

Birch usually is not blazed as is spruce but is split after it is cut to stove length. Birch is the only wood in Alaska which can be burned green. In burning green birch, care must be taken not to let the fire get too low because it takes a hot fire to dry and ignite the green wood. Green birch smoulders for some time until it is dry, then burns rapidly; such a fire must be watched closely.

When necessary, cottonwood and aspen can be cut, dried, and used for firewood; in fact, when dry they burn with a hot flame, but the fire is of short duration and leaves much ash.

The wood is hauled to the site of operations and stacked on crosspieces which keep it off the ground, sawed into lengths and split if necessary, then stored in a shed, tent or under a tarp.

Above timberline every bit of fuel must be utilized, and the knowledge of what can be so used may mean the difference between being able to remain in an area or being forced out. Willows and alders when dry make a quick hot fire, even better for cooking than spruce or birch. They should be cut, limbed, and piled, to be sledged or carried to camp when dry. When dried and roped together, a large bundle can be carried. On any new creek, dead standing alders and willows are available and for the first few weeks furnish cooking fuel. Many times, patches of spruce are found several miles above the regular timberline and can be made to furnish double the amount of fuel normally expected if the stumps and roots are dug out. (The roots in the permafrost areas are just under the surface). Stumps and roots contain much pitch and produce a hot flame.

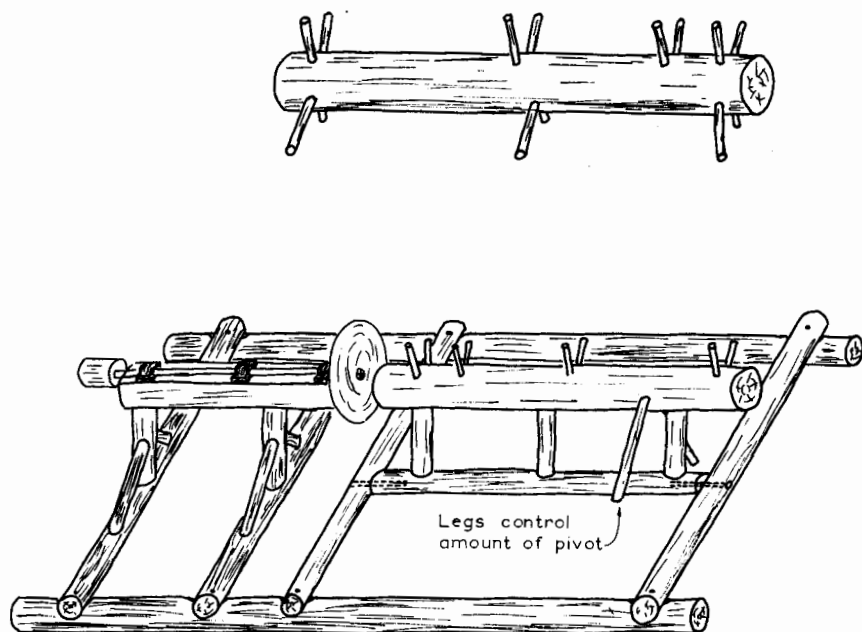


Fig. 17-9. - Saw Buck and Buzz Saw Built Entirely of Logs

In those areas of Alaska in which coal occurs, the possibility of burning coal should be investigated. A stove with a grate is necessary when using coal. When the prospector must go to such an elevation that absolutely no wood is available, he must carry a Primus stove and kerosene. Such a stove which will enable him to spend several days without native fuel but, of course, is not feasible for long range work.

The Swede saw, good for trees up to about 12" in diameter, is preferable to a cross cut saw for cutting small wood and should be kept set and sharp with the special tools designed for that purpose. If larger trees are encountered, a five foot crosscut saw is used. An axe weighing about 3 1/2 lbs is necessary and a hammer and steel wedges are desirable, although wooden wedges can be made when no steel wedges are available. When traveling, the prospector carries a light, two-pound, single bitted axe with 24" handle. The cutting edge is protected by folding heavy cardboard around it and tying it into position with string. An axe is one of the most valuable tools a prospector can have, and potentially about the most dangerous. It must always be treated with the utmost respect but never with fear. It must be kept sharp; a razor-edged axe is safer than a dull one and many times as effective. A file and round pocket axe stone (carborundum) should be kept on hand for sharpening the axe as should extra handles. Emergency handles can be made by substituting a handle meant for one tool onto another, but the prospector must remember that shovel handles are of ash, and break quickly if put on a striking tool such as a hammer or axe.

For cutting wood into stove lengths, the prospector makes a saw buck. This is a log about 6 feet long and 12" thick with four peg legs and six pegs projecting up to hold the wood being sawed. In a large camp, or if a boiler is in steady use, it may be economical to use a buzz saw. Power may be furnished with a separate gas engine, a steam engine, a drill motor, or a power take-off on a tractor. A simply built buzz saw is illustrated in Fig. 17-9. If much wood cutting is contemplated, the purchase of a gasoline powered chain saw may also be advisable.

In high country, where the wood is twisted and tough, straight grained pieces, when found, should be set aside for kindling. These are split and a supply kept near the stove. As needed, two or three pieces can be whittled into shavings and kept with the rest. These shavings are the best kindling, and in winter must always be ready to be ignited at a moment's notice. The

cabin is never left without a supply of kindling and of matches. When traveling, the prospector must leave kindling, matches, and enough wood to last several hours in any shelter cabin he occupies, for to come in cold, hungry, and tired from a hard day only to find no wood is discomforting, and in extreme cases, fatal.

In the winter the prospector melts snow for water. A bucket is made of a 5 gallon can. When the water level drops to one half, the water is heated on the stove and the bucket filled with snow. As four or five men together use too much water for this method, they must keep a barrel in the cabin near the stove. In the summer, creek water is used. Care must be taken that the creek water is not poisonous, as it sometimes is in heavily mineralized areas. In such a case, a water hole is dug, usually near the main stream or in a nearby watercourse.

For camp living any cooking pats or pans are satisfactory; dishes should be of enameled steel. For traveling, aluminum dishes and pots (not cups, however) are lightest and best, and some prospectors use "nesting pats," kettles of graduated sizes so that the smaller will fit inside the larger and take up less space. Some use tin cans with wire handles, which can be thrown away when the trip is finished. Cans with tin linings, not lacquered, should be used. Pots are left blackened as they will absorb heat much faster and save time and fuel.

On short trips or for all summer in high latitudes, what light is needed is furnished by simple white miner's candles preferably of the size that will fit a miner's candle holder. A kerosene lamp furnishes more light at less cost than do candles, but is fragile and impractical when much moving is necessary. For all winter, when the prospector is inside much of the time, a gasoline or kerosene (Aladdin) mantle type lamp is best. It gives excellent light, far superior to that of candles or kerosene lamp, although it uses more fuel than does the kerosene lamp.

Today, bedding almost always consists of sleeping bags as they provide more warmth for their weight than do blankets. For traveling, the army mummy type is superior to anything so far devised. The inner bag alone is sufficient in summer, and in winter the mummy bag is used with an outer bag, which may be opened up if necessary. In very cold weather it is wrapped in a tarp. Where weight is no disadvantage, any one of several excellent larger down-filled bags are preferable, as these are roomier and more comfortable than the mummy bags. They are used usually when the prospector is established in one place for the winter. Blankets, quilts, or cotton, wool, or kapok sleeping bags may be used in a good shelter or in the summer, but are unsatisfactory for sleeping in tents in cold weather because of the great bulk necessary.

Under the bedding, spruce boughs are the universally used mattress. They are laid down facing in one direction so that the large ends of the ones laid down first are covered by the springy tips of those laid on later. The boughs may be covered with a canvas, oilskin tarp, caribou hides, or nothing at all.

During mosquito season, a bed net is often draped over the bed. Fly spray is sprayed in cabins or tents, or buhach is burned. Today DDT "bombs" have largely replaced the older insecticides because they are easy to carry and very effective.

FOOD

The type of food which can be used varies with the locality and the season. If packing across country, the prospector uses mostly dried food because of the necessity for cutting down on weight. If food is being moved in cold weather, and will be exposed for more than a day or so, certain freezable foods cannot be used, and in warm weather certain other foods will not keep. In general, whether moving across country with a pack or snug for the winter in a cabin, the prospector uses more dried food than canned food. If possible, of course, he will use what he might consider "luxuries," such as fresh potatoes, eggs, condensed milk, canned tomatoes, etc. If a summer's outfit is being moved just before the breakup, all these items can be taken; they will not freeze if kept wrapped in bedding. They should be wrapped and left at the landing site, then moved on the first trip.

In most regions in Alaska, even though some game food can be obtained to supplement the basic outfit, it cannot be depended upon. Game should be killed only in the open season and the prospector should familiarize himself with the game laws. Moose, deer, and caribou are in season in the fall when most prospectors attempt to obtain their winter's meat supply. Caribou are prime from August 20 to late in September; after which the bulls become strong and inedible until November. Moose become tough and gamy, although not strong, after October 1, and sheep are prime until about November 3.

Skins are best in late August at which time they are short haired and soft, and the hides of animals killed then should be saved for bedding and various other uses. (The younger animals have the best fur). Good quality caribou skin from the legs is in demand by the Natives for making boots; the legs should be skinned right down to the hooves; the forelegs slit down the back and the hind legs down the front.

Cow caribou generally are poor meat, although legal to shoot; cow moose can never be shot legally. The best caribou meat is found on the biggest bulls, and for that reason the leaders are usually shot (except during October). Black bears are often killed and used for

food; the younger ones are most palatable although old ones may be acceptable. Grizzlies and brown bears usually are too strong to eat, but with any type of bear the flavor seems to depend upon what the bear has been eating. Even strong bear meat is not wasted as it may be used for dogfeed. (Again the game laws should be consulted). Sheep meat is excellent food, but the labor involved in hunting sheep sometimes makes the meat prohibitively expensive for the prospector.

Even if big game is not obtained, the prospector can profit much by shooting small animals, the only kind that should be shot on cross country summer trips. Ground squirrels, although not usually thought of as game, may be used in case of an emergency. Upland birds, such as spruce hens, willow grouse, and ptarmigan, are in season during the late summer, fall, and most of the winter. Ptarmigan and rabbits often are snared with loops of picture wire, and ground squirrels may be trapped. Twenty-two or twenty-two special rifles are used for the smaller game (the special is nearly obsolete; modern twenty-two long rifles are replacing them). If a man is an expert pistol shot, he may carry a twenty-two long rifle pistol for small game. Usually, however, the pistol does not pay for its weight.

The most popular rifle for moose, caribou, and bear is the 30-06, although some prospectors prefer the 30-30 as an all purpose rifle because it is light in weight. Some large rifle should be carried at all times when in bear country, and it should be of 30-06 caliber or larger. This statement may be challenged by men who have spent almost a lifetime in the hills without being molested by a bear. Even these will admit, nevertheless, that men are attacked and killed occasionally, and the infrequent exception is the one against which the prospector must guard. If protection against bears is the prime consideration, something like the .375 magnum should be used. A handgun should never be carried for bears.

If a shotgun is to be purchased, the 12-gauge is the most practical size. Ammunition should be kept cool and dry as dampness is the chief deteriorating agency. If old (more than five years) cartridges are to be used, a few should be tested beforehand to determine if they have full power. Some old ammunition stored under adverse conditions is worthless.

Game, as soon as shot, should be bled and gutted and allowed to cool. If big game is piled in a confined space before it is cooled, it will sour.

The prospector may catch fish as he travels through the country in the summer and for this purpose he should carry a light line and a few flies or spoons to use with a willow pole. In general, however, if he is working on a particular property, he will be several miles from any fishing waters. The same applies to waterfowl, which are usually obtained in marshes, while the prospector's time is spent on the higher creeks and hills. Certain non-game fish, pike, ling cod, whitefish, and others may be netted, providing a good source of food.

To what extent the prospector is able to take advantage of the game resources of the country depends on the season, the region, what can be utilized in the time available, and upon the prospector's hunting ability. In general the prospector only kills game when the opportunity presents itself in the course of his prospecting, except in the fall, when a few days' hunting may be rewarded with a whole winter's meat supply.

Different sections of the country afford varying opportunities for acquiring game food. Southeastern Alaska has deer, black bear, and abundant fish. The Yukon-Tanana plateau and parts of the Brooks and Alaska Ranges have caribou. Moose are fairly well distributed over the entire state, except for Southeastern Alaska and the Arctic areas. Sheep inhabit all of the mountains. Black bears inhabit Southeastern Alaska and the timbered parts of the rest of the country. Grizzly bears are found in the higher ground over most of Alaska; brown bears south of the Alaska Range, and polar bears through the Arctic region. Along the Arctic coast, seals and walrus also provide much food. The meat of all animals named is edible, although some is more palatable than other. The only exception is the liver of the polar bear, which contains so much vitamin A that it is poisonous.

Small game or fish taken during the summer presents no storage problem as it is eaten soon after it is killed. Big game usually is killed in the fall, after the weather has cooled sufficiently for the meat to keep. In late August, while the weather is still warm, the meat should be hung in a well ventilated, screened meat house to prevent flies from blowing it. Even though the weather is not freezing, the meat so hung acquires a "glaze" (dry crust) and usually lasts until freezing weather sets in, depending, of course upon the locality and the seasonal conditions. Lacking a screen house, the meat may be hung under a cache or other shelter in such a way that it is well ventilated. The crust which soon develops ordinarily is enough to keep flies from affecting the meat, except in cracks and corners, which must be cut away. Cheesecloth or bednets may be draped around the meat or pepper liberally sprinkled on it to keep flies away. Meat so handled can be kept for several weeks except in hot weather.

The only problem involved during the winter, is keeping the meat from drying out. This difficulty may be overcome by keeping a coating of ice on the meat, or by burying it in snow, wrapping it in paper, or leaving the hide on the carcass.

If much meat is left over in the spring, it may be "jerked"—cut into strips about one inch square, and hung upon poles to dry in the sun. It soon becomes hard and black and may be stored in sacks or boxes in a dry place. Upon soaking it is cooked for human food or the less

desirable portions fed to the dogs directly. Such "jerky" loses some of the vitamins present in fresh meat and should not be depended upon for fresh food.

In areas of permafrost where the ground temperature is several degrees below freezing, prospectors have from time to time dug freeze holes or drifts. The top of a shaft is lagged, with plenty of moss outside the lagging, and a platform is built about eight feet down, insulated with more moss, and fitted with a trap door covered with hides. Another platform is built near the top, and the platform and the surrounding ground is covered with moss, sod and dirt. Entry is made through trap doors, and only one door at a time is ever opened. The area around the shaft must be well drained with a good ditch which extends well into the frozen ground, because if water following the frost line enters the shaft, it will spoil any meat inside and might cave the shaft. It is best if the meat is frozen when put into the hole, but thawed meat can be frozen, although the outside may mold in the process.

The wild vegetables and berries of Alaska provide variety in the diet during the summer but in most cases do not contribute materially to the food supply. Blueberries are the most important, and even a handful in the sourdoughs makes up for the lack of many items found only in more settled areas. Blueberries may be preserved without treatment if stored in a cool place, and if a plentiful supply is found close to the base of operations, enough can be picked in a couple of days to last most of the winter. Many use a scoop consisting of wood or wire fingers about three inches long and fastened to a pan or container to catch the berries. Berries picked with a scoop contain leaves and twigs and are cleaned by rolling them down a blanket held at a slight angle; the leaves and twigs are left behind and discarded. Other less abundant and consequently less valuable berries are low bush cranberries, high bush cranberries, raspberries and "solmon" berries. The true salmon berry grows in Southeastern Alaska on a high bush. In the Interior and Arctic sections of Alaska a yellow berry growing close to the ground is also called "salmon berry". Other names for this particular berry are "cloudberry" and "baked appleberry". Low bush cranberries are made into cranberry sauce; high bush cranberries are good for jelly when picked before fully ripe; raspberries and salmon berries are eaten fresh.

Other common edible vegetables are rose hips, very sweet and nutritious after the first frost; wild rhubarb, cooked as domestic rhubarb, but requiring more sugar; and lambquarters, the young leaves of which are cooked as greens. Rose hips are so rich in vitamin C that the cooked products retain enough to provide an anti-scorbutic food through the winter. Mushrooms, of course, provide food in season, and although they are lacking in calories, they contribute variety to the food supply. However, the prospector would be wise to learn to distinguish one or two which are edible, and to gather them only.

Dozens of plants can be eaten in an emergency, and the reader is referred to "Wild Edible and Poisonous Plants of Alaska", by Christine A. Heller of the Cooperative Extension Service, College, Alaska.

As stated before, the prospector cannot rely on finding game to supplement his diet but must take enough food to see him through. Then if game is obtained, so much the better. It might be pointed out that obtaining a winter's meat supply saves several hundred dollars on the grocery bill.

The following remarks and suggestions have been found by experience to apply to Alaskan conditions. Dry pack or brine butter outlast canned butter if kept in a brine solution in a five gallon tin-lined bucket. Margarine keeps best of all and is being used more and more. Treated eggs are becoming difficult to obtain, and if fresh eggs are to be kept any appreciable length of time, they should be coated. Eggs are purchased perfectly fresh, dipped in the thinnest mineral oil obtainable, allowed to drain overnight, and repacked. No. 5 mineral oil is satisfactory, and it should be warmed to about 100° to make it thinner. Eggs may also be kept in a crock or jar and covered with waterglass (one quart of waterglass to nine quarts water). Another method is to preserve the eggs in limewater. Two pounds of lime are scalded in a little water and stirred into five gallons of water. After the lime has settled, the clear liquid is poured over the eggs in a crock. Fresh eggs should be stored in a cool corner of the cabin on the floor. If the temperature is close to freezing they will keep for six months. If eggs become wet, they must be recoated. Eggs must not be frozen, and if it is seen that freezing is inevitable, they should be cracked open, the contents beaten lightly, and quickly frozen in wax-lined cardboard containers. They should be kept frozen then until ready for use. Fresh potatoes should be stored at a temperature of about 45°; if colder they become sweet and watery. If they must be frozen, they should be kept that way, and when needed quickly peeled and dumped into boiling water before they start to thaw, or boiled with their skins left on. If frozen potatoes are allowed to thaw slowly, they become black and soggy. The same treatment may be applied to fresh cabbage, and with slightly less satisfactory results to several root crops. Condensed milk usually will bear freezing once but becomes curdled if frozen again. However, it may still be used for most cooking purposes even if curdled. Dried yeast should not be kept in the house; if frozen all winter, it keeps better than indoors.

Bacon and ham intended for use during the summer should be "heavy smoked". As this type is becoming difficult to obtain, mild cured meats being preferred by the general public, the prospec-

tor should specify "heavy smoke". Mild cured ham is easily fly-blown; the maggots then infest the meat around the bone, and it should be examined periodically in warm weather. The best treatment for mild cured ham and bacon which must last through hot weather is to hang it over an alder smudge for a day or two, covered with a canvas or burlap tent. Bacon or ham which has been wet must be similarly resmoked. Mold is removed from ham and bacon by swabbing with a weak vinegar solution; all ham and bacon should be coated with cooking oil before hanging. Occasionally ham and bacon are furnished in an asphalt coating. While this covering protects them from flies, it promotes molding, adds weight, and is not recommended.

During the gold rush days when dried food was in more demand than now, a larger variety of such food was available. However, a fairly good selection of dried fruits and vegetables can be obtained today, and improved transportation makes up any inconvenience caused by the added weight of canned or fresh vegetables.

Bread is usually baked once a week in summer or once a month in winter if enough oven space is available so that large batches can be made. Much difficulty is experienced in making bread or sourdough rise in a tent in cold weather, consequently bakery bread should be hauled to the site if tent living during the winter is planned. On extended trips a reflecting oven can be used for baking. It folds flat and weighs about three pounds. For short trips, bannock, essentially baking powder biscuit dough cooked slowly in a frying pan, is most practical. The dough is often mixed right in the top of the flour sack.

Soluble tea and coffee, although a little more expensive than the regular kinds, is often justified when traveling light across country.

Food should be packed differently for the various methods of transportation. For back packing, most of the food should be in small canvas sacks made for the purpose. Holes in canned milk can be sealed by sticking a bit of paper—some from the label will do—to the can and using the milk as glue or by plugging the holes with bits of butter or covering with adhesive or Scotch tape, candle wax, etc. For general hauling by plane, tractor, or dogsled, especially where several reloadings are necessary, small strong cardboard boxes well tied with stout cord should be used. Flours and cereals should be in cloth sacks, not paper. Formerly, wooden boxes were much used, but now they are difficult to obtain and in addition, add weight; but a few wooden boxes should be included to furnish boards for a table, shelves, etc. One box, well marked, should contain food to be consumed while on the trail and should be a small outfit in itself. The contents of each of the other boxes should be known. One way is to list the contents on the outside of each box; another is to number each box and to write the proper box number opposite each item in the invoice (duplicate sales slips issued by the store are usually used).

When buying an outfit, the prospector should inquire if a discount is given on large orders. It is also a good policy to buy locally if a store is maintained in the area, although this is becoming increasingly difficult due to centralization of Alaska's population. Buying locally from a reputable merchant usually insures that food will be packed adequately for the type of transportation to be used, that impractical or unnecessary items will be pointed out, and makes a friend and advisor for the prospector where he needs it, near his base of operations.

Several sources have been consulted in compiling the following suggested ration lists. More than one is given to illustrate the difference in type of food used under differing conditions. All sources agree that one man will consume from three to five pounds of food per day or from 90 to 150 pounds each month, depending on how much dried food is used.

List 1 - One man, one month, summer
(After von Bernewitz, from Ontario Dept. of Mines).

Flour or bread	22 pounds	Bacon	12 pounds
Salt pork	3	Butter or oleo	4
Beans	3	Rice	3
Raisins	1	Cornmeal	2
Roll'd Oats	4	Salt	2
Pepper	2 oz.	Condles	12 (each)
Corn syrup	5 lbs.	Tea	1 1/2
Coffee or cocoa	1	Baking Powder	1/2
Dried apples	1 1/2	Dried apricots	1 1/2
Dried peaches	1 1/2	Dried prunes	1 1/2
Sugar	15	Bouillon cubes	1
Pat Barley	1/2	Split peas	1/2
Dried potatoes	2	Dried milk	5
Dog Salmon/dog or	30	Total	101 lbs.
Corn meal	30		
Dog tallow	10		

The syrup could be dispensed with and a little sugar added. The amounts of tea and coffee should be adjusted to suit the individual. In this list and the following one, prepared pancake flour can be substituted for some of the flour.

Contrasted to this list is the following, from Peele, page 10-80. The food listed was consumed in a mining camp of 25 men in 30 days. The figures have been reduced to terms of one man for 30 days. The extra weight of food consumed is due to the use of fresh food and to waste.

Evap. apples&apricots	0.8 pounds	Beef	25.4 pounds
" prunes & figs	1.5	Pork	6.3
Baking Powder & soda	0.2	Bacon	3.4
Dried beans	1.8	Ham	5.5
Dried peas	0.5	Canned fruit (10's)	3.6 cans
Butter	4.2	Canned vgs(10's)	2.9 cans
Cheese	0.8	Condensed Milk,tl	16 cans
Coffee	2.8	Sardines	1.2 cans
White flour	19.0	Soap	2.8 bars
Graham flour	0.7	Crackers	0.5 pounds
Raisins, currants	0.6	Cereals	1.6
Rice	0.5	Vinegar	0.2
Rollod Oats	0.75	Salad Oil	0.1
Salt	1.9	Shortening fats	2.4
Macaroni, spaghetti	0.7	Sugar	16.7
Tea	0.08	Yeast	0.02
Cabbage	4.1	Carrots	3.2
Onions	4.0	Parsnips	1.5
Potatoes	22.3	Turnips	2.0
Eggs	5.2 dozen		

Spices, condiments, and flavorings were in addition to the above. The average daily consumption was 7 pounds per man.

These lists should not be taken at their face value but should be modified to meet conditions and preferences. The first list provides an austere diet which could well be rounded out by dried potatoes, canned meat, oysters, clams, cheese, dried soup, chocolate candy, jam, and other items. If not back packing, a small tub of salted salmon bellies may be taken to provide fish in the diet. On the other hand, the second list, included to show approximate consumption in a large camp mess, could be revised to save weight and money.

The following list is suggested for a month's trip for one man during the summer months in Alaska.

White flour	15	Baking powder	1 pound
Sugar	15	Salt	1
Bacon	8	Ham	8
Canned corn beef	8	Powdered eggs	2
Powdered milk	3	Coffee	2
Tea	1	Dried fruit	6
Cheddar cheese	5	Chocolate candy	2
Butter or margarine	4	Pilot bread	2
Jam	3	Dried potatoes	2 (diced)
Dried potatoes(instant)	2	Dried onions	1/2
Dried cabbage	1	Dried carrots	1
Dried spinach	1/2	Pudding Powder	2 (precooked)
Canned clams	1 1/2	Canned salmon	4
Beans(lima, navy, red)	4	Pepper, cinnamon,	
Dried soup	3	bay leaves	1
Shortening	3	Rice	3
		Cereal	5
Per dog: Dog salmon	30	Total	119 1/2 pounds
or			
Dog tallow	10		
Cornmeal	30		

If traveling across country the prospector could dispense with some of the canned items and take more easily prepared foods. For instance, more of such things as pilot bread, dried soup, precooked pudding, chocolate, and cheese might be taken, and less beans, rice, and flour, even though these last named are just as light weight for their food value as the others. Shortening might be passed up for bacon grease. If an extended stay at a base camp is planned, on the other hand, more variety can be achieved by the addition of salt salmon bellies, ketchup,

more flour with yeast for bread, a few canned vegetables, condensed milk, more canned meats, etc. Ready mixed flour for biscuits, bread, hotcakes, cake, cookies and the like are obtainable and save much time.

CLOTHING

Interior

In summer the Interior probably requires less in the way of specialized clothing than does either Southeastern or Arctic Alaska. In the Interior, the most practical clothing consists of light "shoepacs"—rubber bottoms with leather uppers; felt insoles, wool socks, long underwear, from 25 to 100 percent wool; denim, duck or light woolen pants, and heavy cotton or light wool shirt. A light jacket, such as blanket-lined denim, a wool cap with a visor, and several pair of cotton work gloves complete the outfit. Enough clothing must be worn to give protection from mosquitoes. During the warmest part of the spring, summer, and fall, a canvas or felt hat is preferable to a cap because it sheds rain and can support a mosquito net. A lightweight slicker should be carried, although "tin" clothing is worn for rainclothing by some. When wet, however, this becomes stiff and the coats, at least, are shunned by many for this reason. For use in camp, the best slippers are those made from the rubber bottoms of worn out shoepacs ("stags"). Extra clothing should, of course, be kept in camp.

When the prospector travels on foot through the country the only extra clothes he carries are socks and insoles. In late years, twelve inch rubber boots have found favor among some Alaskans. These keep the feet drier, but are hotter and snag easier. For short trips, hip-length rubber boots (called gum boots) may be worn. Such boots enable the prospector to ford streams easily and are useful while running drains and panning streams, but they too are heavy, hot, and easily snagged. There are three grades; the lightest weight should be worn for traveling. In Canada and the Northern States, waterproof leather boots are worn in summer. Of course, the choice of footgear is a personal matter, but much of Alaska is either wet or cold, or both, and experience has shown that shoepacs provide the best service for varying conditions. Being warmer than leather boots, they can be worn from early spring until early winter, protecting the wearer from temperatures which would cause frozen feet if leather boots were worn. Shoepacs may be obtained in different weights and shapes.

During mosquito season, some men wear a veil-like net which suspends from the hat brim, but of late years these have fallen into disuse because new mosquito repellents are so effective that nets are seldom necessary. Sometimes a handkerchief is suspended from the hatband to give protection to the back of the neck. Adequate protection must be provided against mosquitoes in June, July, and early August. Under the worst mosquito conditions, a man with no immunity to mosquito bites and without proper clothing and repellents may be driven practically insane, or at least reduced to the point where he can accomplish nothing but fight mosquitoes.

In winter in the Interior, heavier underwear, more socks, cold weather footwear, and heavier outer clothing are worn during times the prospector is away from camp. In winter, a prospector is not moving through the country looking for outcrops or doing general reconnaissance work because the ground is snow covered. His winter work consists of sinking shafts or driving drifts on lode or placer ground. For such work he dresses more or less in his summer clothes except when working on the surface. For freighting, woodcutting, or other work requiring him to be away from camp, he wears wool pants, heavy wool shirt, moccasins, wool coat, and wool or fur cap. In extremely cold or windy weather, he wears a knee length parka of canvas or moleskin with wolverine ruff and wrists. Some also wear large overalls over the wool pants and one or two sweaters. Mittens consist of wool liners and leather outers (choppers) or native made moosehide and wool mitts hung on a special harness so that they can be removed and put on easily. As these mitts are too bulky for working, they sometimes are left off for several hours while lighter gloves are worn. At such times the strings of the harness are twisted behind the back so that the mitts are held there out of the way until needed.

Moccasins vary in size and shape. The Hudson Bay type is manufactured of domestic hide and if not obtainable in Alaska, can be ordered from Canada or the Northern States. All others are native made and cost from \$3.00 to \$25.00 per pair. The warmest are of moose hide bottoms and caribou or reindeer fur uppers. Insoles and felt boots or caribou skin socks are worn inside the moccasin with as many pairs of wool socks as desired.

During the spring, snow boots, moosehide bottoms with canvas uppers, are sometimes worn outside of felt socks. They keep snow from getting into the clothing, are cheaper than skin boots, and are dried easier. The Army in Alaska issues snow boots made with domestic leather, and hundreds of pairs have found their way into surplus stores. These, with the accompanying felt socks, are satisfactory substitutes for native moccasins; the only disadvantage being that they are slippery.

Felt shoes are good cold weather footgear if deep snow is not encountered or if snowshoeing is not necessary. These, too, have been supplanted by the Armed Forces in Alaska and may be obtained cheaply. During the last few years, the "thermal boot", consisting of a double lay-

er of rubber with insulation between the layers has also made its appearance. For certain types of work the thermal boot is excellent, especially if drilling or shaftsinking in winter where it is necessary to be continually moving from wet surroundings to an extremely cold atmosphere. The boot provides a combination of waterproof and cold-proof qualities not found in other footwear but is too heavy for much walking. All winter clothing and footwear should fit loosely.

Southeastern Alaska

In Southeastern Alaska although summer clothes are designed more to protect from the rain, they are about the same as in the Interior. Summers are cooler than in the Interior, so woolen clothing is comfortable. Slickers are essential, and all-rubber boots, sou'westers, and rain pants may be worn to good advantage.

In winter, clothes designed for slushy snow conditions are best. These include almost the same ones as worn in summer, except that woolen liners and leather chopper mitts are better than cotton gloves, and a woolen cap may be worn under the rain hat. Back in the mountains, conditions approaching mild Interior winter conditions exist. Shoe-pacs, mackinaws, winter cap, and mitts should be worn. As a precaution, should the prospector be caught in a storm, a drill parka should be carried.

Arctic

Arctic conditions prevail in a strip along the coast from Bristol Bay north and east to the Canadian border. In the south, this strip is narrow; in the north, it occupies the entire slope north of the Brooks Range. In the Brooks Range and interior Seward Peninsula, conditions partly Interior, partly Arctic, exist. Summer weather in the Arctic is cool, windy, and often damp. Although

WINDCHILL NOMOGRAM

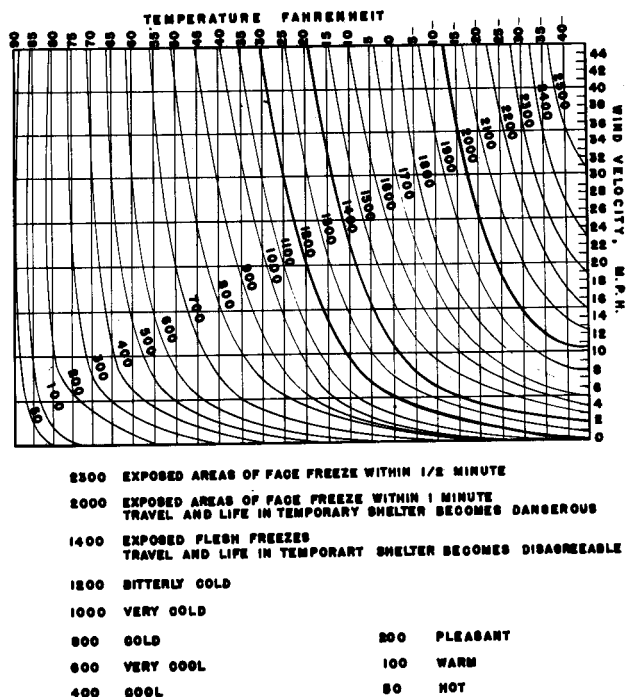


Fig. 17-10 - Windchill Nomogram, Showing Effects of Varying Wind Velocities and Temperatures. U. S. Army photograph

there is little rain, along the coast driven fog soaks through ordinary clothing very quickly. The same clothing as is worn in the Interior, tending more toward heavier wool covered by a slicker, is worn. Arctic weather changes very rapidly, and the traveler should be prepared for foul weather at all times.

Winter weather in the Arctic can be extremely severe. Travelers caught in the worst storms have no alternative except to dig in or die. Prospectors contemplating spending the winter in the Arctic no doubt would be well established so that a snug shelter could be reached easily. In such circumstances, winter clothes similar to those worn in the Interior suffice. Fur boots with moosehide bottoms or mukluks with oogruk skin bottoms should be worn, and if extended exposure is contemplated, native made fur parka, pants and mitts are the best.

All clothing, in any part of Alaska at any time of the year, must be dried often, preferably every night. In winter, snow must be brushed from clothing and footgear before the wearer enters a shelter and particular attention paid to drying during the evening. If not properly dried, clothes deteriorate very rapidly. When possible, they should be kept clean for the same reason. A very small sewing kit, weighing an ounce or two and taking up practically no room, helps to keep clothing, shoes, and harness in repair. Suggested items are skin needles of various sizes, harness needles (used in pairs), strong linen "wax-end" thread (shoe repairmen have it), or dental floss, a ball of beeswax, and harness maker's awl.

In cold weather, an accompanying wind increases the discomfort noticeably. In fact, the great danger in being out in the winter is not so much low temperatures, assuming that accepted winter clothing such as has been described is worn, but high winds accompanying moderately low temperatures. Under such circumstances, which are often encountered in the Arctic, clothing capable of stopping wind, preferably fur, is worn. To compare the effects of different temperatures and wind velocities, a "wind chill" nomogram, reproduced here by permission of the U. S. Army, Alaska, is illustrated in Fig. 17-10.

Chapter 18

ELEMENTS OF MINING LAW; STAKING CLAIMS

INTRODUCTION

Anyone engaged in prospecting must know something of mining law, but he should realize that some of the mining laws are susceptible to more than one interpretation. The laws themselves are short, and upon first reading, seem clear and exact, yet upon each one a great deal has been written by judges in attempts to determine the real intent of the lawmakers. Much of what we call our mining law is made up of court decisions, which have become as much a part of the law as the statutes. Even so, there are many points of law which have not yet been clearly decided.

The Bureau of Land Management is charged with administering the public domain, but it is concerned with mining claims only when they come to patent, and patenting a mining claim in Alaska is the exception, not the rule. There is no pressure upon the prospector as there is upon an agricultural entryman to patent his claim, thereby bringing to a head the question of his compliance with the law. Prior to patenting, so far as the Bureau of Land Management is concerned, if a person is prospecting or mining in the public domain, what legal steps he takes to safeguard his investment of time and money are his business. If another comes along, claiming a better right to a mining claim, that is a personal dispute to be decided by the courts, and the only time the law is interpreted is when such a challenge is made. A challenge may be, and often is, based upon some minor point, and it sometimes seems that no title is safe before patent is issued.

This chapter does not always differentiate as to whether a law is Federal or State. Because States cannot enact mining law in conflict with Federal laws, the State laws always tend to make the law more restrictive than if Federal law alone governed. For this reason, it is necessary to have both Federal and Alaskan laws available when trying to decide upon the legality of some action. Laws governing the staking of ground, with which the prospector is most concerned, are Alaskan.

HISTORY

At the time of the California gold rush, the government and the people had no clear idea of how the unappropriated mineral lands should be taken up. The laws of Mexico and Spain, former owners of California, had provided that miners should lease from the government, acquiring certain possessory rights but obligated to pay a royalty to the government. Many in the United States were in favor of adopting such rules, but nothing was done by the Federal government until 1866. In the meantime, the miners in different camps or mining districts made their own rules. These set the boundaries of the districts, provided for the election of recorders, defined the method of appropriating and holding ground, and in some districts actually set up courts and prescribed "miners' meetings" to settle disputes. Federal civil law was not well established; local courts were just as effective in regulating mining. Local abuses grew so great in places (often the first comers organized a district for their own benefit, to the disadvantage of later arrivals), that a demand grew for Federal legislation. In 1866 the first law was passed, regulating the size of claims, providing for eventual patent, and setting up means of settling disputes. In 1870 the laws were extended to cover placer claims, and in 1872 a comprehensive law was passed, which is essentially the Federal mining law of today. These Federal mining laws apply in Arizona, Arkansas, California, Florida, Idaho, Louisiana, Mississippi, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, Wyoming, and in a modified form, Alaska; they may be supplemented by State or local laws so long as these State or local laws do not conflict with those of the Federal government. These State and local laws cannot deal with the disposal of the mineral lands but only with "locating, manner of recording, and amount of work necessary to hold possession of mining claims".

The Federal mining laws were not extended to Alaska until 1884, four years after gold was discovered at Juneau. There were, of course, no Territorial or State laws, consequently, local regulations were adopted which, for a short time, were the only laws in effect. The local laws for the Harris Mining District are given by Henry Roden in his book, "Alaska Mining Law". There are now no local mining laws in effect; Federal and State laws regulate mining in Alaska.

There are many points of similarity and many of dissimilarity between the laws dealing with lodes and placers. The Alaskan laws deal mostly with placer and are taken up under that heading. They supplement Federal law.

LAWS PERTAINING TO BOTH LODE AND PLACER

Any unappropriated lands containing valuable minerals (except oil, oil shale, gas, coal, phosphates, potassium, or gravel which are acquired only by leasing) may be acquired under the mining laws. Originally, almost all of Alaska belonged to the Federal Government but parts of the public domain have been appropriated by individuals or corporations as mining claims, trade and industrial sites, townships, and for other purposes. In addition, tracts, large and small, have been withdrawn by government agencies as Military Reservations, Indian Lands (and one Indian Reservation), Administrative Headquarters Sites, petroleum reserves, game reserves, and for almost every conceivable governmental use. Of special interest in Alaska are the School Lands and those of the University of Alaska. Sections sixteen and thirty-six in each township in Alaska are reserved for the support of the schools of Alaska. Section thirty-three in each township in the Tanana Valley between 64° and 65° north latitude and 145° and 152° west longitude are reserved for the support of the University of Alaska. An additional 100,000 acres is authorized for the University and is being acquired gradually. These School and University lands must be non-mineral. If they are found to contain mineral when they are surveyed, they will not be set aside for the State but will remain open to entry. If they do pass to the State and mineral is discovered on them later, however, the minerals belong to the State. If a prospector locates a claim in unsurveyed country and finds himself in a reserved section when the surveys are extended, his mineral rights are protected; the land will be withheld from the State because of its mineral content. After all of the appropriations and withdrawals, both private and public have been subtracted from the land, the remainder is open to location of mineral claims. Mineral claims may even be located upon unpatented agricultural homesteads, although a start has been made by the Bureau of Land Management to classify land into potentially mineral land or agricultural land. If found to be potentially mineral, no homesteads may be taken.

Any citizen, or one who has declared his intention of becoming a citizen, may locate ground under the mining laws and may purchase such ground from the government by receiving a patent. However, an alien may locate ground under the mining laws, and hold it against all claimants except the United States Government, and since the Government has never challenged such a claim, essentially an alien has the same rights before patenting as a citizen. He may not acquire mining property by patent, however. The only other persons prohibited from locating mineral claims are employees of the Bureau of Land Management and of other agencies whose positions might give them an unfair advantage over the public.

Qualifications for persons acquiring mining claims or leases on State lands are the same as those on Federal lands except that persons acquiring such lands must be 19 years of age.

It might be stated here that the Government seldom challenges the right to an unpatented claim; it is when application for patent is received that the Government becomes particular that the locator has complied with the law. Not complying with the law leaves the locator open to challenge at any time by other individuals or agencies of the Government, however.

Acquiring Mineral Claims

Assuming that the land is open to location and that the locator is qualified by law to make a valid mineral location, there are three requirements which must be fulfilled.

First, there must be a discovery of valuable mineral. There is no standard for the discovery, only that "valuable mineral be found in such quantity and under such conditions as would justify an ordinarily prudent person, not necessarily an experienced miner, in expending further time, labor, and money upon the property, with a reasonable expectation of developing a paying mine". A lode discovery must be made in place; float of valuable ore does not suffice. A placer discovery consists of valuable mineral mixed with the unconsolidated material overlying bedrock. The discovery must be within the confines of the claim in either type.

The second requirement is that the claim must be marked upon the ground and a location notice posted (the prescribed methods of marking and posting the claim will be described when placers and lodes are considered separately).

The third requirement is that a certificate of location must be filed for record in the office of the Recorder for the appropriate Recording District. The law grants the locator 90 days from the date of posting of the location notice in which to file the location certificate. He may file later if no intervening rights have ensued, but no such rights can ensue for the 90 day period. The location certificate must include all of the information contained on the location notice, plus a description of the location of the claim with reference to some natural landmark, so that an intelligent person, reasonably familiar with the country, could find the claim; once he has found it, the claim is supposed to be well enough marked so that it can be traced. Permanent stakes of nearby patented claims can be used in place of a natural landmark. Usually lode claims are "tied" to a ridge, dome, or peak and placer claims to the right or left side of a creek, a stated distance from the head or the mouth. The content of the location certificate is rigidly

prescribed, and it must be followed exactly. If a mistake has been made in the location notice or certificate, or if the locator wishes to change the position of his claim or its size, he may post an amended location notice and file an amended location certificate. In it the same information as was included in the original should be stated and, in addition, the changes and reasons for them. The fact that it is an amended notice or certificate should also be stated.

It is immaterial which of the three acts is done first, but usually they are performed in the order given: discovery, location, and recording. As stated, a person who has made a discovery and staked his claim is protected in his right for 90 days before he must record his location certificate. However, if he has made no discovery, merely having staked the claim, another may make the discovery, stake, and record, thereby acquiring the ground. The first man is entitled to the actual space he needs in his work until the second has completed his legal requirements, whereupon it all passes to the second. This is not likely to happen except during periods of excitement and stampedes. Since the outcome of a court contest between two such men would depend upon proving that the first prospector did not make a discovery, and as this is a difficult thing to do, most prospectors hesitate to locate ground in conflict with another on such a basis. Besides, trespassing and creating breaches of the peace are prohibited by law, and anyone who does either does not help his case in contesting another's title to a mining claim.

The three acts: discovery, staking, and recording perfect a mining claim. The fee simple title to this claim rests with the Government, yet the locator enjoys most of the rights of ownership, so long as he complies with the law. Although the lode location and the placer location each convey possessory rights, the lode location is superior to this extent; the locator of a lode claim acquires any placer which might be contained on the lode claim; the locator of a placer claim does not acquire any rights to a lode which might be buried beneath his placer. To acquire rights to the lode he must stake a separate lode location.

The holder of any mining claim, placer or lode, however, controls the surface against other individuals as effectively as if he owned it outright. Futile lawsuits and, worse, shooting tragedies have occurred because men have not realized this. It is true that the locator of a placer claim does not acquire rights to lodes upon the claim, yet no one is entitled to enter upon the claim to prospect for lode, unless he can do so without trespassing. To do this the lode prospector must, or at least he should, have the permission and authorization of the placer locator before he begins. No valid claim may be based upon fraud or breach of peace. If the lode discovery is made outside the placer claim and the lode locator merely includes a portion of the placer claim within the lode claim, no trespass occurs and the lode claim is valid. The lode locator is entitled to an area extending no more than twenty five feet on either side of the centerline of the vein where it crosses the placer claim, but the two locators must make up their minds to get along and not to interfere with each other's operations.

It has been stated previously that the holder of a valid mining claim controls the surface against other individuals. Prior to July 23, 1955, he also controlled the surface against the Government. On that date Public Law 167 was passed, providing that until patent is issued, the Government can dispose of the timber and manage other surface resources of the claim. The claim owner may cut and use timber for mining purposes but may not dispose of it or use it for purposes unconnected with mining. The surface rights of claims located prior to July 23, 1955 can be protected by appropriate action. Inquiry should be directed to the Bureau of Land Management office nearest the claim. With the advent of this law, the Bureau of Land Management has taken a more active role in settling disputes between the holders of mining claims and others wishing to acquire the surface rights for other purposes.

The Act of Congress which allowed Alaska to have Statehood granted the future State the right to choose approximately 100 million acres of the unappropriated Federal lands during the next twenty five years. It was stipulated that mining claims already in existence within any such lands remain in full force and effect, but that the State would get the mineral rights to any unappropriated land and could only dispose of these mineral rights by lease.

The State of Alaska adopted the policy of allowing prospectors to search for and appropriate mineral rights in accordance with the mining laws under which Alaska has traditionally operated. Therefore, a prospector may enter State lands just as he would Federal lands, and if he should discover a mine, appropriate it, develop it, and mine it as in the Federal lands. He may, however, not patent it, and if he should insist upon patenting, the State would be obliged to lease the mineral rights to the highest bidder. It is safe to assume that no one would care to apply for a patent to a mining claim in State land.

Although the State laws pertaining to mining and prospecting were purposely kept similar to Federal laws, a number of significant changes were made. The following gives, very briefly, the most important of these changes.

First, "locatable minerals" are defined as those which may be located under Federal law. Next, deposits of locatable minerals may be acquired by staking claims if they are in one or more of the following classifications:

- (1) Grazing lands
- (2) Material lands
- (3) Mineral lands
- (4) Timber lands, or
- (5) Unclassified lands.

If the prospector mistakenly stakes a claim on ground which must be leased, he can convert his claim to a lease. (See the section on leasing lands in which minerals, even if locatable, may be acquired solely by leasing.)

A very important difference between State and Federal law applies to the actual size of a mining claim in State lands--there is no distinction made between lode claims and placer claims. The maximum size of either can be only forty acres and the maximum dimension 1320 feet. Under Federal law, as will be seen, such a claim would correspond to a forty acre placer association and would have to be staked by more than one man and would require \$200 worth of assessment work each year.

Assessment Work

Another requirement of the law applying with equal force to both lode and placer is the necessity of performing assessment work annually. This is the only stipulation made by the government in order for one to hold a legally acquired mining claim. At least \$100 worth of work must be done on each claim annually. If the claims are contiguous, work may be done all on one claim, provided that \$100 worth is done for each claim or for each 20 acres of a placer association staked after August 1, 1912. If more than one owner is involved, each owner must have an interest in each claim. The requirements for association claims staked before August 1, 1912 are considered later. The \$100 may be paid to another, or the owner or some other interested person may do the work without any money being involved. The value of the work is then computed at the wages and rates current in the district.

The assessment year formerly began and ended at noon of July 1 of each year; now it begins and ends September 1 at noon. Extra work performed in one year cannot be carried over to the next year; that is \$200 worth of work cannot be done one year and none the next.

The law does not say specifically what constitutes assessment work, but numerous decisions give a clear picture of what may or may not be considered. If the prospector is serious in his intention of proving the worth or worthlessness of his claim and works toward that end, no one will doubt him. Work which obviously helps to develop the ground is actual digging, clearing brush, if it is necessary to exploration or preparatory to mining, constructing buildings (these must be on the claim), or cutting wood and timbers which are later used in working on the claim. Merely placing wood or equipment on the claim, brushing out lines, buying tools, or spending money for transportation is not allowed as assessment work. Work may be done off the claim if it tends to develop it. Such work might consist of building roads, trails, ditches, pipelines, or airfields.

In general, the provisions for assessment work on mining claims on State lands are similar to those on Federal lands, except that only \$100 worth of work need be done on the larger forty acre claim or fraction thereof. On Federal land, \$100 worth of work must be done on each twenty acres or fraction thereof. There is doubt whether the survey for patent may be considered assessment work for one year, and it is safest not to depend on such a consideration. Brushing claim lines likewise is work of doubtful value when applied to annual assessment work.

If a prospector resumes work at five minutes before noon on September 1 and a second party arrives to restake the ground, the first man's claim is valid, but he must continue his work in the new assessment year until it is completed. For many years there was in force in Alaska the so called "Waskey Act", named for Alaska's first Territorial delegate, who secured its passage. Part of this act, dealing with filing affidavits of annual labor, is still in effect. A part which was repealed, however, stated that if the assessment work was not performed upon a claim during any one year, the owner lost the claim forever. The law was meant to correct certain abuses, but in the opinion of many, introduced injustices. For instance, if a prospector spent five years on a claim with indifferent results, then let the claim lapse by not doing the assessment work for one year, he could not regain title by any means short of buying it from a later locator. A second party who had never expended a bit of money or time on the ground could enjoy the full benefit of the mining laws in locating and holding the claim. Henry Roden, in "Alaska Mining Laws", describes a lawsuit in which a miner was required, under this provision, to prove what kind of work had been done on his claim for each of eighteen years. Unable to do so for one year, he lost the suit and also the claim. After the repeal of this portion of the Waskey Act, and until 1957, it was merely necessary that the prospector resume work on a claim before any intervening right was instituted, and a claim was never really lost no matter how much time elapsed, until someone else staked it.

The claim in the foregoing example need not have been lost, had affidavits of annual labor been filed each year. Federal law provides that a person doing assessment work may file an affidavit of annual labor within 90 days after the expiration of the assessment year (by December 29). This affidavit should be filed in the same office as was the certificate of location; the filing fee is \$1.50 per claim. It must contain the following information:

1. The name or number of the mining claim and where situated
2. Amount and kind of work done, and value of improvements placed thereon
3. Dates or date of performing labor and placing improvements

4. At whose instance and for whose benefit the work was done
5. The actual amount paid, if any, and by whom paid.

If such an affidavit is filed within the allotted time, the burden of proving non-performance of assessment work is on another if he should contest the claim. That part of the Waskey Act still in effect states that if the affidavit of annual labor is not filed within 90 days after expiration of the assessment year, "-----the burden of proof shall be upon the claimant to establish proof of such work -----". This is generally interpreted to mean that the burden of proof is on the prospector if he does not record his affidavit of annual assessment work. Henry Roden gives a sample form of affidavit in "Alaska Mining Law".

In 1957, the Alaska Legislature passed a law making it compulsory to file an affidavit of annual assessment work. This law states that, as before, if the affidavit is filed within 90 days, the burden of proof is upon another who might claim that the work was not done. However, and this is the crux of the new law, after January 1 if the affidavit has not been filed, another may assume that the work was not done and relocate the ground; if this happens, the original owner loses all rights to the claim. If the original owner files his affidavit of annual labor after January 1, however, assuming another has not claimed the ground, he recovers his rights. A further provision states that even assuming no one else locates the ground after January 1, the original owner cannot relocate the forfeited claim for one year or until the following January.

A person having a lien or claim upon any mining property may do the assessment work, thereby securing an additional lien of \$100 plus traveling expenses. Before doing so he must notify the owner in writing a reasonable time before the expiration of the assessment year, so that the owner may be given a chance to do the work himself. If a lien claimant does perform such work, he should file the affidavit of annual labor or have it filed, then file a notice of lien for the amount of his work and expenses. This lien notice should state:

1. The name of the owner or reputed owner
2. The amount of lien claim
3. The time the work was done
4. The kind of work done.

As with any other lien, this must be filed within 90 days of doing the work, and if not settled, suit for foreclosure must be brought within six months after filing.

When a person attempts to do his assessment work upon a claim and is prevented from doing so by one who has relocated it, the claim will not be allowed to lapse because of the non-performance of work at that time. Any forfeiture of the claim must be based upon some other fact.

A claim can be relocated before an owner has legally forfeited his rights only if it has been abandoned by the original owner. Abandonment should be clearly stated before witnesses, although it is not absolutely necessary. A relocater of an abandoned or forfeited claim gains possession of permanent fixtures which his predecessor may have placed upon it. In this respect the mining law corresponds closely to the law which decides what improvements of a tenant may pass to the landlord upon the tenant's moving away. Moveable buildings, tools, etc., do not become a part of the property, but it has been held that stationary engines, fastened to the ground, do.

Occasionally it has occurred that a person has obligated himself to do the annual assessment work on another's claim, then neglected to do it and staked the claim himself or had a friend stake it. No such scheme will convey any title to the person staking the ground (such a person in a confidential relationship is said to be a "fiduciary"). The title shall be considered as held in trust for the rightful owner.

Upon securing a permit from the nearest land office, the prospector may cut for his own use up to 100,000 board feet, or 200 cords of wood, upon the public domain in any one year. This is restricted to persons, not groups or corporations, living in Alaska, and there is no charge. One cord of wood and 500 feet board measure are considered equivalent, and it is immaterial which is taken, saw logs or cordwood, so long as the limit is not exceeded. If more wood or timber is needed, he can secure the right to cut it upon the payment of a certain stumpage rate.

LAWS PERTAINING TO LODES

The geological definition and the legal definition of a lode are the same; if the valuable mineral is discovered in place, it must be appropriated as a lode. Float is what the lode prospector searches for, and its presence may betray the proximity of a lode, but float is not enough on which to base a lode location.

After the prospector has found a lode in place, he should do enough work so that he can determine the strike of the lode, then place his discovery stake or monument at the point of discovery. To this stake (or among the rocks of the monument), he attaches his notice of location. A satisfactory container in which to place the notice is a flat tobacco can nailed or wired to the post. The notice should state:

1. The name of the lode claim (many fanciful names are used, often conjuring up thoughts of great wealth)
2. The name of the locator or locators
3. The date of the location
4. The number of feet in length claimed along the vein each way from the discovery point and the width on each side of the center of the lode or vein.

The lode claim cannot be more than 1500 feet in length nor extend for more than 300 feet on either side of the vein. If of these maximum dimensions and of rectangular shape, the claim will contain about 20.6 acres. The prospector decides how he will stake the claim, either having his discovery in the middle of the claim or nearer one end than the other, and sets out his center end stakes in line with the strike of the vein (theoretically on the surface of the vein), and not more than 1500 feet apart. He then sets his four corner stakes, not more than 300 feet on either side of his center end stakes. Two claims cannot be staked with one discovery by extending each for 1500 feet each way from the discovery. The claim need not be rectangular, and it may have bends along its length; if it bends, the inflection points on each side of the claim must be marked with stakes (see Fig. 18-1). If a claim is accidentally staked too long or too wide, the owner may cast off the excess by moving his stakes. If some point or corner of the vein is inaccessible, a witness stake may be set, on which is posted the distance and direction to the true position. The minimum number of stakes necessary to locate a lode claim is six: if one end center stake serves also as a discovery stake or seven if there is a separate discovery stake somewhere in the interior of the claim. The boundaries of the claim should be marked by auxiliary posts or by blazing trees or brush.

It is not necessary that the end lines of a lode claim be parallel, but if they are, certain benefits called extralateral rights are gained. Extralateral rights may become very involved where complex vein systems are encountered; here they can only be stated in simplest terms.

If the claim is staked with non-parallel end lines, the prospector is entitled to that much of the vein on which he made his discovery as is contained within the imaginary walls which are the boundaries of his claim projected vertically downward. In addition, he may be entitled to other

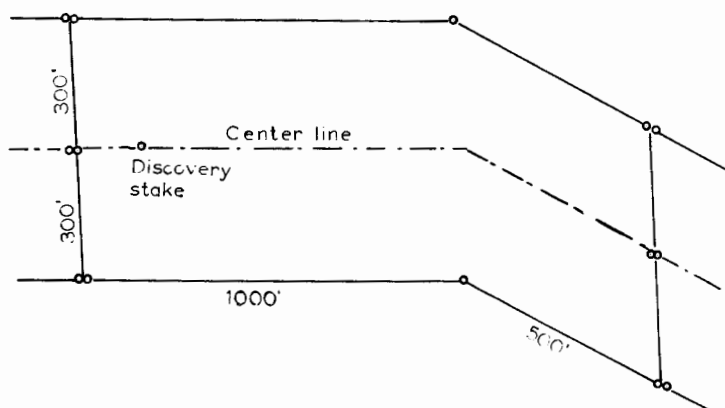


Fig. 18-1 - Lode Claim, Showing Contiguous Claims on Ends.

veins which he may discover within his claim boundaries in the course of his underground work, provided that someone else does not enjoy extralateral rights upon the veins. If the vein has a vertical dip, it will be contained within the projected sides of the claim and can be followed until it bottoms. If it is inclined at some angle, however, it may pass outside the claim at depth and, if someone else owns a claim on that side, the miner must stop when he reaches the side line.

If the prospector has staked his claim with parallel end lines, however, he could have followed his vein down as far as he wished, no matter whose property it may have gone under, because he would have had extralateral rights. From this it is seen that if a person enjoys extralateral rights and he owns the claim upon which a particular vein crops out, or at least where it reaches the top of bedrock, then he owns the rights to the whole vein. That part of the vein reaching the surface is called the apex. The distinction between parallel and non-parallel end lines is made because if they are not parallel, they will take in an increasing amount of vein at depth if they diverge or a decreasing amount of vein, coming finally to a point, if they converge in the direction of the dip. If they are parallel, they will take in only a length along the vein equal to the length of the claim on the surface. There is always the possibility that the vein may not strike as was first thought, and it may actually enter and leave the claim by the side lines, in which case the courts have ruled that the side lines become the end lines. For this reason, it is advantageous to have the side lines as well as the end lines parallel. In such a case, the side lines of course, will be too far from the center, so the prospector, to be safe, should immediately reduce the size of the claim. Fig. 18-2 illustrates extralateral rights.

Where the veins do not occur as simple planes or gently curving surfaces, the legal relationships are more involved. A few variations and the laws regarding them are: when two veins join at depth to become one, the miner having the prior claim gets the intersection and the vein below. If a vein is so wide that two claims may be staked side by side upon it, the prior location enjoys extralateral rights to the whole vein, assuming he fulfills the other requirements of the law. Upon a horizontal blanket vein there are no extralateral rights. Where a vein enters by an end line and leaves the claim by a side line, extralateral rights may be enjoyed upon that part which apexes on the claim, an imaginary end line being drawn from the point where the vein crosses the side line. If a person wishes to stake a lode claim upon an irregularly shaped fraction, he may set his stakes upon the property of another merely for the purpose of having parallel end lines. He gains no rights already held by the owner of the first property and owns only the original fraction, but by having parallel end lines, even if they are off his claim, he gains extralateral rights to any vein that apexes on his fraction.

These few examples illustrate the difficulties which may be encountered in determining extralateral rights. It has been said that extralateral rights have caused more lawsuits in mining than any other reason. The facts often are obscured by lack of a true picture of the vein relationships at depth, which contribute to a lack of understanding between contending claimants. For these reasons, in certain districts mining companies enter into agreements waiving extralateral rights.

There is no limit on the number of lode claims that can be staked except that a discovery be made on each. A person may stake any number of claims for another without a power of attor-

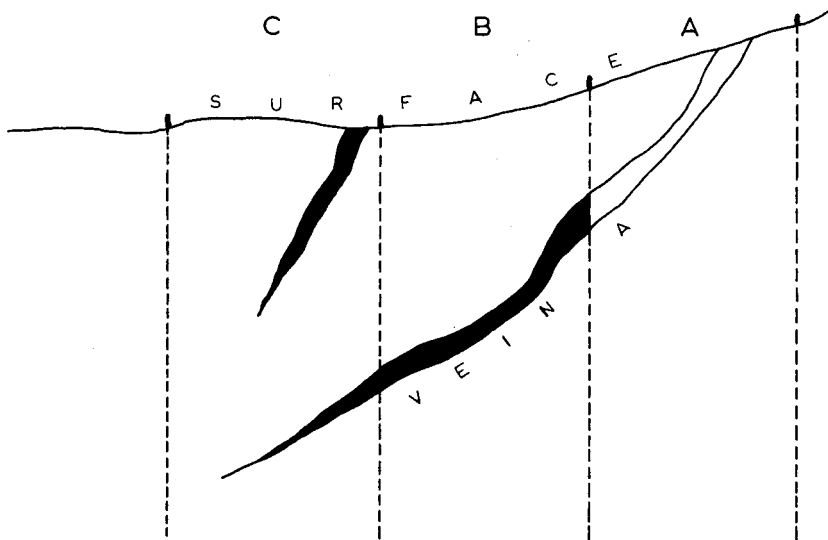


Fig. 18-2 - Extralateral Rights. Cross Section through Three Adjacent Lode Claims. If "A" has extralateral rights, he owns that portion of Vein A shown solid. If not, then "B" and "C" own it.

ney, without even the other having advance notice of the intention. The only stipulation is that the person staked in will accept the claims.

LAWS PERTAINING TO PLACERS

In Alaska, competition for placer ground always has been keener than for lode ground. For this reason, the Alaska Legislature has, from its inception, enacted rules regulating the staking and holding of placer claims. When the legislature did not have the power to deal with a specific problem, Federal legislation was requested. Prior to August 1, 1912, a placer claim of from twenty to 160 acres could be staked so long as there was one person for each 20 acres. A claim of any size up to the maximum could be located with only four stakes and required only \$100 worth of work annually. This is still the Federal law, but it has been amended by many State legislatures. For Alaska the so called "Wickersham Placer Act" of Congress abolished the 160 acre claim in 1912. From 1934 to 1939, 160 acre claims were again legal, but \$800 worth of work an-

nually was required. It is not known whether any such claims dating from that interval now exist. At present a person may stake two twenty acre claims each month in any one recording district, or he and any number of other persons may stake two forty acre association claims each month in any one recording district. A third possibility is that he may locate one twenty acre claim by himself and one association with others. If more than two persons stake an association claim, each receives less for that month than authorized by law, for the law says that a person may stake two twenty acre claims or (with others) two forty acre association claims a month in each recording district.

Alaska law requires \$100 worth of assessment work on each claim or upon each twenty acres (or fraction thereof) of an association claim. Federal law requires only \$100 worth of work for a whole association claim.

A placer claim must not exceed twenty acres nor an association claim forty acres. The maximum lengths are 1320 and 2640 feet respectively. Sometimes wide creeks are staked with square association claims 1320 feet on a side. Claims in the creek are called creek claims and those on the bench are called bench claims. On wide creeks sometimes several parallel rows of bench claims are staked; the row nearest the creek is called the first tier, the next is the second tier, and so on. If it is discovered that a claim has been staked too long or too wide (for its length), the locator is given a chance to cast off the excess. Presumably, another wishing to locate the excess must notify the original locator of his intention. This interpretation applies only when the excessively large location had been made by an honest mistake. Almost all claims are laid out by pacing so that such honest mistakes are by no means uncommon. Placer claims may be given names (associations often are), but usually the first claim on a creek is called "Discovery" and others numbered "above" or "below" discovery. Where a placer claim is staked on land already surveyed, the claim should conform to the legal subdivision. Usually, this is not convenient, and results in more claims being staked to cover a section of creek than would be necessary if the claims were laid off along the creek. However, if the claims are patented, a considerable amount of money is saved in surveying fees. The only areas in Alaska where placer claims are likely to be staked upon surveyed lands are those close to incorporated towns or in the coal fields.

A placer claim is located by simply staking the four corners and any bends or angles, if such occur. On one of the stakes the location notice should be posted (again, it is usually in a tobacco can). The location notice should contain:

1. The name or number of the claim
2. The name of the locator or locators
3. The date on which the location is made
4. The number of feet in length and width claimed.

In addition, the boundaries must be marked so that they can be followed easily, either by auxiliary stakes or by blazing trees and brushing lines. The name or number of the claim and the post number must be marked on each post. Posts are numbered in rotation. At least four stakes are required for each claim; and where two claims adjoin, two stakes must be set at the common corners. Fig. 18-3 shows a placer claim.

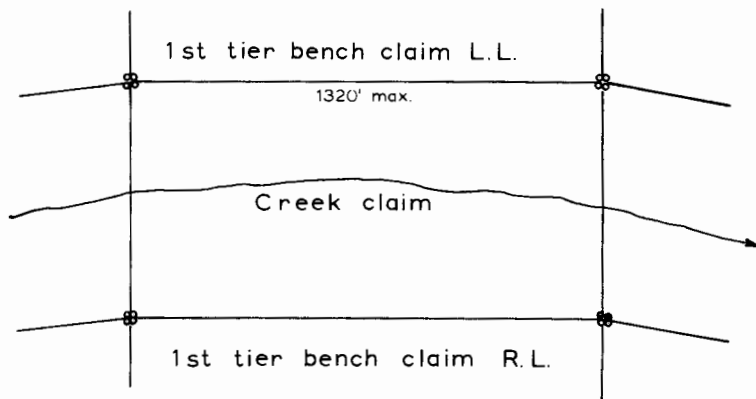


Fig. 18-3 - Placer Claim, Showing Bench Claims on Sides and Contiguous Creek Claims.
R.L. = Right Limit; L.L. = Left Limit

What constitutes discovery on a placer claim varies greatly. On the surface, it could be a tiny speck of gold; on bedrock; it would have to be considerably more. A discovery must be made on each claim.

A person may locate two placer claims each month in any one recording district for one other person or one claim for each of two others; these he can stake in addition to his own. In order to do this, he must have written power of attorney which has been recorded previous to the location, but not more than four years previously.

TUNNEL SITES - PROSPECTING SITES

A tunnel site is not a lode claim, but an area, 3000 feet square, in which a prospector has certain exclusive rights. He may keep these rights unmolested so long as he prosecutes his work with reasonable diligence. If he should cease work for six months, he loses the rights gained by his location of the tunnel site. The following defines his rights and also his duties.

First, a prospector decides that he has a reasonable chance to find a lode underground, and to this end decides to drive a tunnel (actually, an adit). He decides upon the direction or line of his adit and where the portal will be and posts a notice at that point. The notice must contain:

1. The name of the party claiming the tunnel right
2. The actual or proposed course or direction of the tunnel, the height and width thereof, and the course and distance from the "face" (portal) to some permanent well known object in the vicinity by which to fix and determine the location of the tunnel site, the same as must be done in the case of lode locations
3. Establish (describe) the boundary lines of the tunnel location by stakes or monuments placed along its lines at proper intervals to the end of the 3000 feet from the face (portal) of the tunnel or adit.

He then stakes out the center line, 3000 feet along the direction of the tunnel, and sets an end stake; then sets corner stakes 1500 feet to the right and left of the end stake at right angles to the center line. Two more corner stakes are set 1500 feet each way from the portal, with the center line of the tunnel thus bisecting the site. The outside boundaries are marked by blazes or pickets.

Within 90 days he must file in the office of the recording district, a copy of his location notice, plus an affidavit stating:

1. The amount expended by him and his predecessor (if any) in prospecting work in the tunnel.
2. The extent of the work performed.
3. That he intends, in good faith, to prosecute work on the tunnel for the discovery of a vein or veins.

The holder of a tunnel site is entitled to any veins not previously known to exist and not appearing on the surface, which may be cut by his tunnel. The provisions that the lode must not have been previously known and that it must not appear on the surface work no hardship on the prospector, for if a vein was known or did appear on the surface, it could have been acquired with a lode location.

If a lode or vein is discovered in the tunnel, the discovery should be followed by the other two acts required to acquire mineral land; namely, staking a lode claim and recording a location certificate. The discovery will suffice for one claim 1500 feet long by 300 feet on either side of the vein; the 1500 feet may be taken in either direction or in both directions from the discovery point. The position of the outcrop, or apex, of the vein upon the surface should be computed and marked off (this is a job for a competent surveyor) and the claim staked accordingly. Even so, the claim, as staked, may miss the apex entirely, so some surface prospecting should be done to find the apex. The location notice should state the same facts as other lode location notices plus the fact that the discovery was made in the tunnel and should give directions for reaching the tunnel and the discovery point. As a further precaution, a notice may be posted at the point of discovery underground. Upon completing the lode location, the tunnel site ceases to exist. The holder of a tunnel site cannot afford to drift blindly through barren rock; he must have very good evidence leading him to believe that a valuable vein can be discovered without much tunneling.

On State lands a right similar to a tunnel site may be acquired as a prospecting site. The prospector may stake a maximum of 160 acres, not to exceed 2640 feet on any side. The boundaries, which should run north-south and east-west so far as possible, are marked adequately, with double stakes at the corners. The prospecting site must be tied into a monument or natural marker.

The prospecting site is good for one year, but if a diligent search for mineral is being made, it may be extended for one year periods if application is made at least thirty days before the right expires. During the first two years, work worth \$5 per acre must be done, and \$10 per acre thereafter. In general the other provisions are similar to those for mining claims, except that if the prospecting site lapses, the locator may not stake it again for two years. No person may stake more than six prospecting sites in any one calendar year.

MILLSITES

The last type of location provided for under the mining laws is the millsite, a five acre tract which may be taken near a lode claim for the purpose of erecting a mill. There are two ways in which a millsite may be taken up: by the owner of the lode claim, to be used in connection with the claim, or by one who wishes to erect a mill to do custom milling for others. No title to a millsite taken for this latter purpose ensues until actual operations start.

A millsite taken by the owner of a nearby lode must be:

1. Non-mineral
2. Non-contiguous to the lode claim
3. Used or occupied by the owner of the lode in connection with the development or working of the lode.

The millsite may adjoin a lode claim on a side line. The site may be of any reasonable shape; usually it is square or rectangular. A location notice should be posted on one corner, all corners set, and the boundaries marked. The recorded location certification should contain a description tying the site to a natural object. The law does not specify how a millsite should be staked but it is safe to assume that the location notice should contain all the information appearing on a mineral location notice, except, of course, the discovery notice, and in addition it should contain any pertinent information, such as the lode claim or claims for which the millsite is taken, the fact that the land is non-mineral, etc.

No annual assessment work is required for a millsite; use for the purpose intended is the most important factor in establishing right.

On State lands a millsite may be acquired by staking, after which an application is made to the Director of the Division of Mines and Minerals. A "reasonable rate" shall be charged, and the millsite shall remain in force so long as it is not used for some purpose other than that for which the permit was granted.

WATER RIGHTS

Water rights may be acquired like other possessory rights and maintained for the exclusive use of the possessor. Like other rights, water rights are based upon (1) claiming the water by a certain legal procedure, (2) developing it, and, (3) finally, using it.

After it is decided where a ditch or flume will tap a source of water, a notice should be posted at that point, stating:

1. Amount of water appropriated
2. The location of the point of diversion
3. The place or places where it is intended to be used
4. Purpose for which it is to be used.

A copy should be recorded within ninety days.

The water should then be diverted from its natural bed (constituting development) and finally, it should be put to the use for which it was appropriated.

The point of intake may be changed at any time if such change does not interfere with any rights acquired subsequently by another. If another is using the water after it discharges from the first appropriator's ground, the place of use cannot be changed so that the second person is left without its use.

Since 1959, anyone planning to use water must notify the State Commissioner of Fish and Game of his intentions.

LIENS

If a workman in or around a mine is not paid for his services, he must take steps to protect his interests like any other worker. Within 90 days of terminating his work, he must file in the office of the appropriate recorder a lien claim, which must contain the following information:

1. A true statement of the amount due after deducting all just credits and offsets
2. The name of the person by whom the lien claimant was employed
3. A statement of the terms and conditions under which the lien claimant was employed, giving first and last days of employment
4. A description of the property on which the lien is claimed, sufficient for identification
5. The name of the owners or reputed owners of the property on which the lien is claimed.

The lien claimant or someone having personal knowledge of the facts must swear to the correctness of the claim.

The lien claim, when properly executed and filed, ties up for 90 days the property named therein, so that it cannot be sold, adjudged, or otherwise disposed of. The lien claim itself does not confer any other benefit upon the claimant; it insures that, should he bring suit within 90 days, the property of his employer will be available to be attached to enforce payment of the judgment. After 90 days, the claimant can still sue, but he must take his chances with

other creditors on a first come, first served basis, and there is always the chance that his former employer may dispose of the property before he may claim it.

Liens can be used to enforce claims for wages for an interval extending back no longer than nine months; if a man worked longer than that without wages, he has not helped his case. (One of the fundamentals of law is that the law helps him who is alert and prosecutes the enforcement of his just claims with vigor).

A situation often arises where a prospector leases his ground to a miner who hires men and buys materials on credit. The prospector, naturally enough, does not want his ground or other property to be tied up by lien claims nor sold to satisfy someone else's debts. He can protect himself by posting a notice in three conspicuous places about the mine that he himself is not mining and is not liable for any debts contracted by the operator. This notice must be posted within ten days after the owner gains knowledge of the operation. Others, such as mortgagees or former lien claimants having an interest in the ground or equipment, may also post of non-liability.

GRUBSTAKE AGREEMENTS

A common financial arrangement in the past, and to some extent today, is one whereby someone with a regular income furnishes the supplies and transportation necessary to maintain a prospector in the hills for a period of time. Usually they agree to each take a half interest in any ground that the prospector might locate during the life of the agreement.

It is not necessary to have the agreement in writing to bind the two parties, but to be safe against the attacks of others, it must be written and the signatures witnessed by two people. The best policy is to have the signatures acknowledged and to have the agreement recorded. This agreement should show:

1. The time during which it is to be in effect
2. The exact acts required of each party
3. The interest or share that each is to receive.

PATENTING

Patenting is the final step in a long series of acts beginning with the discovery of mineral in the public domain. After patent is issued, 90 percent of the claim owner's troubles are over. No one can contest his title if he has been alert in his application, except the Government, and then only if perjury or fraud is proved. He may have trouble with extralateral rights but no more than if he had taken an agricultural homestead. Note earlier in this chapter that mineral rights in State lands cannot be patented.

After \$500 worth of work has been performed upon any lode or placer claim, it is ready for patent. Any number of adjoining claims may be covered by one patent application, and the work may have been done on one or any number of them so long as it averages out to \$500 each. The value of work performed or improvements made on a claim by a predecessor from whom the property was purchased may be counted toward the \$500. The work or improvements of a predecessor who forfeited or abandoned his claim, however, does not count toward the credit of a relocater.

The first step in obtaining a patent is to apply for a survey to the cadastral engineer in the district in which the claim is located. The claimant then selects a surveyor from a list of qualified U. S. mineral surveyors and contracts with him to survey his claim. If the claim is a placer claim and in surveyed lands, the claim should conform to legal subdivisions if possible. This, of course, is a great saving to the claimant. The claimant must at this time deposit funds with the Bureau of Land Management to defray the cost of drafting and other work.

After the survey is completed, the claimant must post upon the claim a copy of the plat of survey, together with a notice of his intention to apply for a patent therefor; this notice must give the date of posting, the name of the claimant, the name or number of the claim, the number of the survey, the mining district and county, and the names of adjoining and conflicting claims.

After posting the plat and notice, the claimant must file with the manager of the proper office a copy of such plat and the surveyor's field notes, accompanied by a statement by at least two credible witnesses that such plat and notice are posted, giving the date and place of posting and a copy of the notice.

At the time the proof of posting is filed, the claimant must file his application for patent. This must be accompanied by a certified copy of each location notice and a certified abstract of title to the claim. It must contain full particulars which will prove conclusively that the land contains a valuable mineral deposit and show of what kind, extent, and tenor. It must also outline the facts upon which the claimant bases his possessory rights and show that he has complied fully with the law. For claims staked since August 1, 1946, the application must state whether the applicant had any part in the development of the atomic bomb and if so give particulars.

If no reason appears for rejecting the patent application, the manager of the land office in which the application is filed will have published, at the claimant's expense, a notice of application. If in a daily newspaper, it shall be in the Wednesday issues for nine consecutive weeks; if

in a weekly paper, for nine consecutive issues. The publishing must run for 60 days, exclusive of the day of first publication, and plat and notice must be posted on the claim for the same interval. The manager of the land office must also post a notice in his office for the same period. The claimant then files proof of publishing and posting.

At any time during the publishing and for a period of eight months thereafter an adverse claim can be made by another who claims an interest in the ground or some portion of it for its mineral content. The filing of such adverse claim stops the process of applying for and being granted a patent, and the proceedings are held in abeyance until the courts decide the issue. The adverse claimant has sixty days (thirty days in the United States proper) in which to commence his suit.

If no adverse claim is filed or if the courts decide in favor of the claimant, the claimant shall be allowed to pay for the land and receive a patent. The price is \$5 per acre or fraction thereof for lode claims and millsites and \$2.50 per acre or fraction thereof for placer claims. If objections other than by adverse claimants are raised, the Bureau of Land Management will conduct hearings to determine the outcome. These objections may be raised at any time up to the issuance of patent; the purpose of this rule is not to prolong adverse claims but to give justice to one being deprived of part ownership or to hear one who has evidence of non-compliance with the law. Sometime before patent is issued, a representative of the Bureau must check on the mineral character of the land and upon the improvements. If this representative is not satisfied, he protests the patent.

If a person is patenting a placer claim and knows of a lode upon the claim, he must mention it in all his notices and applications. If such a lode is not owned by another, he may claim it; if owned by another, he must state so; the patent, if issued, will protect the rights of both parties. If knowledge of the existence of the lode is not stated and it is not claimed, title to the lode does not pass with the patent, and the owner will find himself in the awkward position of having a fee simple title to a piece of ground, yet having to do assessment work on a lode to prevent someone else claiming it. If the existence of a lode on a placer claim being patented is not known at the time the patent is issued but is discovered in the course of placer mining operations after patent is issued, the lode belongs to the owner of the placer claim.

LEASING REGULATIONS

Coal, oil, gas, oil shale, salt, sodium, phosphate, potassium, and gravel are not appropriated under the mining laws but are leased. The Government retains the right to any helium found in leased ground. Lease regulations are being changed rapidly and the latest information should be obtained from the Bureau of Land Management.

Coal

Under the "Alaska Coal Leasing Act" of October 20, 1914 and the amendment of March 4, 1921, the President of the United States was authorized to withdraw certain parts of the Matanuska and Bering River coal lands and not to exceed one-half of all other coal lands in Alaska. The remainder of the coal lands was to be divided into leasing blocks of forty acres or multiples thereof not to exceed 2560 acres. At present the maximum amount of land that may be leased by an individual or group is 10,240 acres, with an additional 5120 acres in special circumstances.

Minerals which can be acquired only by leasing in State lands are the same as under Federal law. In addition, it is also necessary to lease even locatable minerals if they occur on submerged State lands, or on lands sold, leased, or under permit by the State with the mineral rights reserved, or if they occur in one of the following classifications:

1. Agricultural lands
2. Commercial-Industrial lands
3. Private recreation lands
4. Public recreation lands
5. Residential lands
6. Reserved use lands.

On State lands other than submerged lands, the leasehold, as it is called, is staked, claimed, and recorded exactly as is a mining claim. However, since this is a lease and not a claim, a copy of the location certificate must be filed with the Division of Mines and Minerals in order that a lease may be issued. A rental fee of not less than the value of the annual labor per claim per year is charged; this rent begins to accrue on September first following the date of location. Qualified assessment work may be applied against the rental. Rentals may be adjusted by the Commissioner of Natural Resources every twenty years.

A mining lease is issued for a period of 55 years and is renewable. If the lessee fails to comply with the regulations, including assessment work and payment of rental, the lease will be cancelled after due notice. Upon cancellation or relinquishment, the lessee is required to make the premises safe and leave any improvements in good condition. A bond, which may be required before the lease is issued, may be used by the State to guarantee that the lessee will comply with

the terms of the lease.

On submerged lands the leasing procedure is different. The process starts with the issuance of an offshore prospecting permit, which gives the applicant an exclusive right to prospect for two years. An application must be accompanied by a fee payment of \$20, and no person may hold permits for more than a total of 5120 acres. The permit may be extended for one period of two years.

If valuable mineral is found, the permittee is entitled to a non-competitive mining lease, the application fee for which is \$20. In the application, an original and five copies of a plat must be included; the plat must be prepared in accordance with legal regulations. If a lease is issued, the rental rate is ten dollars per acre per year, but certain expenditures may be applied against the rental. The lease is issued for a period of 55 years and is renewable.

In some circumstances, leases may be obtained by offering a cash bonus in competitive bidding, either at public auction or by sealed bids. A notice of lease offer must be published at least once a week for three consecutive weeks and also posted in all offices of the Division of Mines and Minerals. After the cash bonus (offered by the successful bidder) and the rental and bond are paid, the lease is issued to the highest bidder.

A coal lease may be issued for a period of not more than 50 years and may be renewed "on such terms and conditions as may be authorized by law at the time of such renewal".

The first step in acquiring a lease is to make application to the Bureau of Land Management for a lease upon a certain block. Depending on conditions, the block is put up for competitive bidding or leased directly. Only citizens above the age of twenty one or associations or corporations, at least half of whose stock shall be owned by citizens, may hold coal mining leases. The lessee must agree to spend an amount to be stipulated for development of the property, of which not less than one third must be spent the first year and the balance distributed in the next two years.

The cost to the lessee is stipulated in each lease. Royalties of not less than two cents per ton are charged and paid monthly, and an annual rental, payable at the beginning of each year, of twenty five cents per acre for the first year, fifty cents per acre for the second through the fifth years, and \$1.00 per acre for each year of the lease thereafter. The rental for each year is credited against the royalties.

When prospecting is necessary to determine the existence or limits of a coal deposit, the Secretary of the Interior may issue a prospecting permit for a period not to exceed four years. If a commercial deposit is found in that time, the permittee is entitled to a lease on all or part of the ground embraced in the permit. Requirements as to who may receive permits and the amount of land allowed are the same as for leases. The applicant must post a bond of not less than \$1000 to insure that he will comply with the terms of the permit. A ten dollar filing fee is charged.

A limited license or permit, commonly called a free use license, may be issued to persons qualified to lease coal lands for a period of two years, renewable, and for an amount not to exceed ten acres. This entitles the permittee to prospect for, mine, and dispose of coal for strictly domestic and local needs. There are no royalty or rent charges, although there is a \$10 filing fee. The coal may be sold except by a common carrier. Limited licenses should be recorded. Limited licenses are not issued in coal fields in which a coal mine operates under authority of the Secretary of the Interior.

On State lands, a leasing tract of coal consists of any multiple of forty acres up to a maximum of 2560 acres. Such a tract is leased by competitive bidding. If prospecting must be done, a prospecting permit may be obtained for a two year period, renewable for two years if justified.

The lease specifies a royalty to be paid, not less than five cents per ton, and an annual rental which may start lower but which, after the fifth year, shall be not less than one dollar per acre. Rentals may be credited against royalties for any one year. Leases are for an indefinite interval upon condition of continued operation. Royalty rates must be reviewed at least every twenty years.

Oil and Gas

On Federal lands there are two categories of oil leases: those on lands within the geologic structure of a producing oil and gas field and those outside of such a structure. Outside of producing fields, they are leased to the first person to apply. When simultaneous filings are received, the Bureau of Land Management must decide which takes priority. In the structure of a producing field, oil lands are leased to the highest responsible bidder in competition.

Lessees must be citizens over twenty one or groups or corporations in which at least half the stock is owned by citizens. Citizens of countries denying our citizens or corporations like rights are barred from stock ownership in corporations holding leases. Leases are for blocks of not less than 640 acres nor more than 2560 acres, although more leases can be obtained for development as a unit. The maximum area which can be leased by an individual or group is 100,000 acres. All land covered by one lease must be within a six mile square area.

If within the surveyed public lands, the leases are to be taken up according to legal subdi-

visions. If in unsurveyed lands, the government will survey the leases at the expense of the applicant. In Alaska, this surveying in remote areas is done "on paper", pending extension of the land survey.

The initial lease is for a period of five years, during which time payments are as follows: Ten dollar filing fee at the time of filing; twenty five cents per acre rental at the beginning of the first year, of the fourth year, and of the fifth year. If the lessee commences drilling within his lease period, he is entitled to a five year renewal. The rental on renewal leases is twenty five cents per acre each year. Within the structure of a producing field, the annual rental is \$1.00 per year, unless otherwise specified in the lease. A bond of not less than \$1000 must be posted by the applicant.

After oil or gas is discovered, a minimum royalty amounting to \$1.00 per acre per year must be paid. The royalty on production is twelve and a half percent per year, but at present the law contains an incentive clause stating that the first discovery in a new field in Alaska shall pay royalty only at the rate of five percent of gross production for a period of ten years. Royalties are paid monthly. The lessee must agree to drill and operate enough wells so that the ground will not be drained by surrounding wells, or he may compensate the Government for such damage. If producing, the lease is extended for as long as production in paying quantities continues.

Different leaseholders within one field may enter into a cooperative agreement to work the field as a unit. Such a field is said to be unitized. The Bureau of Land Management usually favors such an arrangement because conservation is advanced thereby. The Bureau must pass on the arrangement, which usually provides for the drilling of a certain number of wells.

One person, group, or corporation may hold leases on no more than 100,000 acres nor options to purchase or otherwise acquire 200,000 acres of leased ground. Options may only be taken for two years.

Leasing regulations in State lands in general parallel those for Federal lands, but again, there are some differences.

Competitive bidding for leases is mandatory if the lands are: tidal or submerged lands, mental health lands, school lands, or University of Alaska lands. In addition, when oil or gas is discovered in a well, the Commissioner of Natural Resources determines the extent of surrounding lands which may reasonably be expected to contain oil or gas, and these lands can only be obtained by competitive bidding. This amounts to almost the same thing as the producing structure of the Federal regulations.

Competitive leases are awarded in units of not more than 640 acres, except in tidelands and submerged lands, where 5760 acres is the maximum. Royalties are not less than 12 1/2% of gross production, except that the discoverer of oil or gas on a new structure pays only 5% for the first ten years.

All lands other than those noted above are open to non-competitive leasing to the first person applying. A leasing unit may not exceed 2560 acres. Royalty provisions are the same as for the competitive lease. Leases are for a primary period of five years and continue in effect so long as production continues.

Non-competitive lessees must pay 50 cents per acre annual rental and competitive lessees one dollar per acre annually after production starts.

Oil Shale, Sodium, Phosphate, Potassium, Gravel

These are also appropriated under the leasing laws under regulations somewhat similar to those governing coal leases. They have been removed from appropriation under the mining laws because they are ordinarily formed by process of evaporation or sedimentation and deposited as blankets. Such deposits do not lend themselves to appropriation as either lode or placer claims. Anyone finding a deposit of any of these commodities should obtain information on leasing them from the Bureau of Land Management if on Federal lands or the Department of Natural Resources if on State lands.

LICENSES AND TAXES

Alaska requires the miner to pay a license tax on his product. At the start of the year or on commencing mining, the license is procured and posted on the premises. At the end of the year, the license tax is paid at the following rate (1955) on net income from the property.

Up to \$40,000	0%
\$40,000 to \$50,000	3%
\$50,000 to \$100,000	\$1500 plus 5% of excess over \$50,000
Over \$100,000	\$4000 plus 7% of excess over \$100,000

Net income is the gross production from mining, operating a reduction works, or royalty, minus operating expenses and overhead. (No expenses may be deducted from royalties.) In addition to these deductions, depletion may be deducted at the following rates:

Coal	10%
Metals, all other except sulfur	15%
Sulfur	23%

Depletion may not be claimed exceeding 50% of net income, computed without allowance for depletion.

All new mining operations, except those mining sand and gravel, are exempted from paying this tax for a period of three and a half years from the date on which production begins (first shipment).

FORMS

Forms for all of the notices, certificates, affidavits, and agreements are contained in Alaska Mining Law by Henry Roden. Printed forms, which need only be filled in, may be purchased from printers in any Alaskan town.

CONCLUSIONS

It has been maintained by some that the mining laws encourage litigation, but there are examples of men who have mined all their lives without ever becoming involved in a single suit, while other men seem to be continually in court. From this it seems that prospecting and mining are to a large extent what the individual wishes to make them. If a person follows the law in spirit as well as in letter and maintains respect for the rights of others, he will find that the courts, the Bureau of Land Management, and the mining industry will stand behind him.

References

- Alaska Compiled Laws, 1949, Bancroft-Whitney Company, San Francisco, California
Alaska, State of, 1960, Title II, Natural Resources, Division 1, Lands, Chapter 6, Mining Rights
Bureau of Land Management, Circulars and Pamphlets
Ricketts, A. H., 1943, American Mining Law, California Department of Natural Resources,
Division of Mines
Roden, Henry, 1955, Alaska Mining Laws, Jessen's Publishing Co., Fairbanks, Alaska
Session Laws of Alaska for Legislative Sessions since publication of Alaska Compiled Laws

Chapter 19

GEOGRAPHY OF ALASKA

GENERAL

The reading of this chapter should be accompanied by frequent reference to any large map of Alaska. Alaska occupies such an extensive area that any attempt to describe it without subdividing it is unsatisfactory. Some different systems of subdivision which have been used are noted briefly, and the one which is being followed in this book is described in more detail.

The miners and prospectors who spread over the Territory and who discovered the different mining camps provided the first system of subdivision. As each new camp was discovered, the discoverers gave it a name, usually that of the major drainage system. Thus there are the Forty-mile, Seventymile, Chisana (Shushana), Kantishna, Iditarod, Innoko, and Kobuk mining camps. Some have changed names; the Circle and Fairbanks camps, when first located, were called the "Birch Creek," and "Tanana" districts, respectively, after the drainage systems in which they were located. A few camps were named for other prominent geographic features, such as capes or bays, and a few others took the name of the principal settlement, which in turn often was named after some prominent man. With time, a reference to the "Fortymile district," "Koyukuk drainage," or the "Iditarod country" became simply "the Fortymile," "the Koyukuk," or "the Iditarod," a practice which continues.

Each camp, as it was discovered, created a need for local civil law and recording facilities. Accordingly, a commissioner's office was established in the principal settlement of the camp, and the judge of the district court defined the boundaries of the district. These boundaries usually followed drainage divides or streams, although they occasionally cut across country. The recording districts, then, represented, in a rough way, the different mining districts. In recent years, as the populations of some of the districts have decreased, for reasons given in Chapter 8, the process of establishing new Recording Districts has reversed itself. The trend today is toward consolidation of districts. In the Fourth Division alone, the Fairbanks district has incorporated within its limits the Kantishna, the Chandalar, the Circle, the Koyukuk, the Eagle, (Seventymile), and the Fortymile districts.

LEGAL SUBDIVISIONS

For legal and political purposes, the Territory was divided into four Judicial Divisions, each of which has a District Court with a judge, a clerk, a district attorney, and a marshal and deputies. Each division was broken down into Recording districts, Voting precincts, and Commissioners' precincts. The area over which the Commissioner had jurisdiction in certain criminal cases and probate matters was usually coexistent with the recording district, and the Commissioner was ex-officio Recorder. There were a few exceptions, however, where a Commissioner had jurisdiction over an area which was part of a larger Recording district.

Under Statehood, Alaska is divided into twenty four Election districts corresponding in many respects to the old Territorial Recording districts or combinations of them. These Election districts are named as follows: 1, Prince of Wales; 2, Ketchikan; 3, Wrangell-Petersburg; 4, Sitka; 5, Juneau; 6, Lynn Canal-Icy Straits; 7, Cordova-McCarthy; 8, Valdez-Chitina-Whittier; 9, Palmer-Wasilla-Talkeetna; 10, Anchorage; 11, Seward; 12, Kenai-Cook Inlet; 13, Kodiak; 14, Aleutian Islands; 15, Bristol Bay; 16, Bethel; 17, Kuskokwim; 18, Yukon-Koyukuk; 19, Fairbanks; 20, Upper Yukon; 21, Barrow; 22, Kobuk; 23, Nome; 24, Wade Hampton. These Election districts are the building blocks from which other governmental units have been built and will be built. Thus, there are four Senate districts- the Southeastern, South Central, Central, and Northwestern districts. These Senate districts are coextensive with four Judicial districts, except for the inclusion of Election district 15, Bristol Bay, with the Election districts of the South Central Senate district. With this exception:

Southeastern Senate district	First Judicial district
Northwestern Senate district	Second Judicial district
South Central Senate district	Third Judicial district
Central Senate district	Fourth Judicial district.

The four Judicial districts of the state correspond almost exactly to the four Judicial divisions of the Territory. The map inside of the front cover shows the Election districts and Senate districts.

Thus the legal subdivisions of the State follow the traditional subdivisions, based on economics and geography, which developed in pre-Territory days and become a part of the

Territorial legal structure. The State now has a Supreme Court and the following lesser courts: A superior Court with eight judges apportioned among the four districts to deal with important civil and criminal cases; District Magistrate Courts, consisting of several District Magistrates and their deputies which have taken over the duties, including the registration of documents, of the old Commissioners' Courts and Municipal Courts. The District Magistrates, therefore, are the Recorders under Statehood. The State Recording districts are almost the same as they were in Territorial days and correspond roughly to Election districts or parts of Election districts. Alaska does not have counties.

The miner or prospector who locates mining ground in Alaska must know which recording district he is in and record his claim in the office for that district. In general, this will be with the District Magistrate or deputy magistrate closest to the claim. However, there are exceptions. The University of Alaska has published a map showing the Recording districts; this map may be consulted in many State offices.

First Judicial District

This district occupies Southeastern Alaska and has its Superior Court in Juneau, the capital of the State. Under Territorial Status, it was divided into eight recording districts, each of which was under the jurisdiction of a United States Commissioner; now magistrates and deputy magistrates have taken over the recording. These districts and the post office serving the magistrate's office of each district are tabulated below:

<u>Recording District</u>	<u>Post Office</u>
Skagway	Skagway
Haines	Haines
Juneau	Juneau(also location of Superior Court and capital of Alaska)
Sitka	Sitka
Petersburg	Petersburg
Wrangell	Wrangell
Ketchikan	Ketchikan
Hyder	Ketchikan (Located outside of recording district)

Second Judicial District

This district embraces Northwestern Alaska from south of the Yukon Delta to east of Barrow. Its court is located at Nome, and its recording precincts are tabulated below:

<u>Recording District</u>	<u>Post Office</u>
Noatak-Kobuk	Kotzebue
Fairhaven	Nome (Located outside recording district)
Cape Nome (Many districts have been incorporated into this one in the past.)	Nome (Location of Superior Court)
Wade-Hampton	Fortuna Ledge

Third Judicial District

This district occupies the area paralleling the Gulf Coast from the Canadian border westward, extending through the Bristol Bay area and out along the Aleutians. The recording districts are as follows:

<u>Recording District</u>	<u>Post Office</u>
Cordova	Cordova
McCarthy	Glennallen (Located outside recording district)
Chitina	Glennallen
Valdez	Valdez
Talkeetna	Palmer (Located outside recording district)
Anchorage	Anchorage (Location of Superior Court)
Palmer	Palmer
Whittier	Anchorage (Located outside recording district)
Seward	Seward
Kenai	Kenai

<u>Recording District</u>	<u>Post Office</u>
Homer	Homer
Seldovia	Seldovia
Iliamna	Anchorage (Located outside recording district)
Kodiak	Kodiak
Kvichak	Naknek
Bristol Bay	Dillingham
Aleutian Islands	Cold Bay

Fourth Judicial District

This district occupies the north central part of Alaska, including the Yukon-Tanana drainage, except for the mouth of the Yukon, and also the Kuskokwim drainage and the extreme northeastern corner of Alaska. Its recording districts are as follows:

<u>Recording District</u>	<u>Post Office</u>
Fairbanks	Fairbanks (Also headquarters of the Superior court; in recent years many districts have been incorporated into this district.)
Rampart	Rampart
Fort Gibbon	Tanana
Manley Hot Springs	Manley Hot Springs
Nulato	Galena
Nenana	Nenana
Mt. McKinley	McGrath (Includes former Otter and Innoko districts)
Kuskokwim	Aniak
Bethel	Bethel

SUBDIVISIONS BASED ON GEOGRAPHY AND GEOLOGY

Because the separation into judicial districts provides a convenient system for the listing of statistics, it is often used in publications dealing with prospecting and mining in Alaska. It is the only subdivision suitable for comparing certain activities, such as the staking of claims or the recording of assessment work. Further, the four judicial districts divide Alaska roughly into four sections having different climatic and economic conditions, which make them acceptable for many types of comparison. They have, however, a legal rather than a geological or mining basis for their boundaries, and, above all, they are subject to change. For this reason, other systems of division have been devised by those connected with the mining industry.

Mr. R. L. Stewart, now retired, of the old Territorial Department of Mines, used the following subdivision in his publication, "Prospecting in Alaska":

Southeast Alaska
 South Central Alaska
 Copper River Region
 Prince William Sound
 Alaska Railroad Region
 Kuskokwim River Region
 Yukon Basin
 Northwestern Alaska
 Northern Alaska

United States Geological Survey Subdivisions

Another classification, which has been used for years by the United States Geological Survey to indicate the areas about which they may be writing, is the following:

1. Southeastern Alaska Region
2. Gulf of Alaska Region
3. Copper River Region
4. Cook Inlet Region

5. Southwestern Alaska Region
6. Aleutian Islands Region
7. Kuskokwim Region
8. Yukon Region
9. Bering Sea Region
10. Seward Peninsula Region
11. Northern Alaska Region

Recently the United States Geological Survey completed the coverage of Alaska by the Alaska Topographic Series maps, which divide Alaska into quadrangles on a scale of 1:250,000 or roughly four miles to the inch. In its statistical work the Geological Survey now uses the quadrangle system of subdivision.

United States Bureau of Mines Subdivision

In 1954, the United States Bureau of Mines worked out a complete division of Alaska into regions, districts, and where desirable, subdistricts. This division takes into account the historical designation applied by the miners themselves and the U. S. Geological Survey system, at the same time standardizing the boundaries along drainage divides. This system is used in this book; the divisions are as follows:

<u>Region</u>	<u>District</u>	<u>Subdistrict</u>
Alaska Peninsula	Alaska Peninsula	Aniakchak
		Chignik
		Kanatak
		Moller
		Pavlof
		Shumagin
		Stepovak
		Ugashik
		Unimak
Aleutian Islands	Aleutian Islands	
Bering Sea	Bering Sea	Pribilof
		St. Lawrence
		St. Matthew
Bristol Bay	Bristol Bay	Becharof
		Clark
		Iliamna Lake
		Katmai
		Mulchatna
		Naknek
		Nushagak
		Tikchik
		Togiak
Cook Inlet-Susitna	Anchorage	
	Redoubt	Chinitna
		Kami shak
		Spurr
	Valdez Creek	Chulitna
		Valdez Creek
	Willow Creek	Matanuska
		Wasilla
	Yentna	Skwentna
		Talkeetna
		Yentna

<u>Region</u>	<u>District</u>	<u>Subdistrict</u>
Copper River	Chistochina	Gulkana Kuskulana Sanford
	Nelchina	Bremner Klutina
	Nizina	Bremner Chitina Nizina
	Prince William Sound	Cordova Lotouche Taznuna Valdez Wells
	Yakataga	Katalla Yakataga
	Homer	Nuka Seldovia Tustumena
	Hope	
	Seward	
	Kodiak	
	Kuskokwim River	
Kodiak	Aniak	Akiak Georgetown
	Bethel	Bethel Nunivak
	Goodnews Bay	
	McGrath	McGrath Tonzona
	Barrow	
	Canning	
	Colville	Anaktuvuk Colville
	Lisburne	
	Wainwright	
	Kiana	
Northwestern Alaska	Noatak	
	Selawik	
	Shungnak	
	Council	
	Fairhaven	Buckland Fairhaven
	Kougarok	
	Koyuk	Koyuk Shaktolik
	Nome	
	Port Clarence	
	Serpentine	
Southeastern Alaska	Admiralty	
	Chichagof	Baranof Chichagof

<u>Region</u>	<u>District</u>	<u>Subdistrict</u>
Southeastern Alaska (continued)	Hyder	
	Juneau	Glacier Bay Juneau Skagway
	Ketchikan	Ketchikan Wales
	Kupreanof	
	Petersburg	Petersburg Wrangell
	Yakutat	Lituya Yakutat
Yukon River	Anvik	Anvik Nulato
	Black	Black Kandik
	Bonni field	Nenana Wood River
	Chandalar	
	Chisana	Chisana White
	Circle	Circle Charley River Preacher
	Delta River	
	Eagle	
	Fairbanks	Fairbanks Salcha
	Fortymile	
	Goodpastor	
	Hot Springs	Cosna Hot Springs
	Hughes	Hughes Melozi Nulato
	Iditarod	
	Innoko	
	Kaiyuh	
	Kantishna	
	Koyukuk	Alatna Wiseman
	Marshall	
	Melozitna	Dall Melozi Tozi
	Rampart	
	Ruby	
	Sheenjek	Porcupine Sheenjek
	Tok	

<u>Region</u>	<u>District</u>	<u>Subdistrict</u>
Yukon River (continued)	Tolovana	Preacher Tolovana
	Yukon Flats	Dall Yukon Flats

The regions are shown on the inside of the back cover of this book.

BROAD GEOGRAPHICAL AND GEOLOGICAL FEATURES

Alaska may be divided into four major physiographic provinces: (1) the Pacific Mountain System, paralleling the Pacific Coast, and extending in places inland for over 200 miles; (2) the Interior Lowlands and Plateau; (3) the Brooks Range, and (4) the Arctic Coastal Plain. These names were given to the areas by Alfred H. Brooks, who however called the third province the "Arctic Mountain System", little suspecting that his name would some day be given to that magnificent range of mountains. The method of division is retained in the most authoritative book on the subject: "Landscapes of Alaska" by members of the U. S. Geological Survey.

Pacific Mountain System

The Pacific Mountain System contains the following Regions: Southeastern Alaska, Copper River, Kenai Peninsula, Kodiak, Cook Inlet-Susitna, Alaska Peninsula, Aleutian Islands, and parts of the Bristol Bay, Kuskokwim, and Yukon River.

Southeastern Alaska, the "panhandle", consists of the long narrow mountainous Alexander Archipelago and a strip of mainland, with mountains rising precipitously from the sea to elevations as high as 10,000 feet. The region is cut by numerous fiords, a few of which penetrate the Coast Range. North of Juneau the archipelago ends, but Lynn Canal extends northward to Haines and Skagway, and farther west Glacier Bay penetrates far inland. From Glacier Bay to longitude 141° 0', the southward extension of the International Boundary, the region consists of a rugged and inhospitable coastal strip of mountains and glaciers. Tremendous snowfields and piedmont glaciers occupy this part of the coast as well as that farther west.

The dominant feature of this part of Alaska is the great curving sweep made by the Pacific Mountain System from Southeastern Alaska, where it is oriented northwest-southeast, to the Alaska Peninsula and the Aleutians, where it runs northeast-southwest. The system is made up of several ranges: The "Coast Range" which is a continuation through Southeastern Alaska of the coastal mountains of British Columbia, merges on the northeast with the British Columbia Plateau and on the northwest ends near the Chilkat River behind the St. Elias Range. This "St. Elias Range" is a northward extension of the mountains in the western part of the Alexander Archipelago, and stretches for 250 miles northwest of Lynn Canal. On the Canadian side, peaks reach to almost 20,000 feet, making the range one of the most inspiring on the continent. The Alsek River penetrates the range and divides it into the St. Elias Mountains on the west and the Fairweather Mountains on the east. Most of the drainage of these mountains is through glaciers.

West of the International Boundary, the system is split into several ranges; the Chugachs are the southernmost. They continue west along the coast and swing south around the west side of Prince William Sound, reappearing on the Kenai Peninsula as the Kenai Mountains.

To the north, on the eastern end of the Chugachs, the Wrangell Mountains, a volcanic group, are separated from the Chugachs by the Chitina Valley. The Wrangells terminate on the west at the Copper River and on the east grade into the St. Elias Range. Farther west, another range occurs north of the Chugachs, the Talkeetna Mountains, separated from the Chugachs on the south by the Matanuska Valley, from the Wrangells on the east by the Copper River Plateau (a broad, featureless basin), and from the Alaska Range on the north and west by the Susitna River.

North of the Wrangells are the Nutzotin Mountains, fronting on the Tanana Valley near the Canadian Boundary; the Mentasta Mountains occupy a like position farther west. The Mentastas terminate on the west at the Delta River; the range continues westward, making a great curve to the southwest, as the Alaska Range. This range, about 600 miles long and 50 to 80 miles wide, contains the highest peak on the North American Continent (Mt. McKinley, 20,300 feet high). The range ends in the region of Lake Clark; other mountains, whose axis is parallel to that of the Alaska Range, but offset to the east, continue southwesterly. These are the Chigmit Mountains containing several active volcanoes. The Chigmit Mountains grade into the Aleutian Range, which continues out along the Alaskan Peninsula and into the Aleutian Islands, gradually decreasing in height and width.

Access to the Interior is obtained by valleys which penetrate this system. Beginning in Southeastern Alaska, Portland Canal, a fiord, reaches the Stewart-Hyder area. Near Wrangell,

the Stikine enters the sea after flowing from the Cassiar Mountains of British Columbia. Just south of Juneau, a fiord, Taku Inlet, leads to the Taku River, heading near Lake Atlin. North of Juneau, Lynn Canal, another fiord, leads to Skagway and Haines. From Skagway, a narrow gauge railway, the White Pass and Yukon, goes through White Pass to Whitehorse. From Haines, an automobile road leads over Chilkat Pass to join the Alaska Highway at Haines Junction. Next to the west, Glacier Bay extends into but not through the mountains. Into Dry Bay flows the Alsek River after having come through the St. Elias Range. Yakutat Bay and Icy Bay, like Glacier Bay, do not penetrate through the mountains.

The first big river entering this stretch of coast is the Copper River, which has practically an all-Alaskan drainage basin. As the river is ascended, it cuts straight through the Chugach Range, an airline distance of about 80 miles. At this point a broad valley, that of the Chitina, enters from the east. As previously noted, this valley separates the Chugachs on the south from the Wrangells on the north. For another 50 miles the Copper River separates these two ranges, then opens out into a large basin, the Copper River Plateau separating the Wrangells on the east from the Talkeetnas on the west. Various tributaries of the Copper River head in passes which provide egress from this basin. Northeast lies Mentasta Pass into Tok River; north, Isabella Pass into the Delta River; northwest, a pass between the Susitna and Nenana Rivers; west, the Susitna is reached across a very low divide; and southwest, a low pass leads into the Matanuska Valley. South, roughly paralleling the Copper River Valley but farther west, a route by various tributaries of the Copper River crosses Thompson Pass, reaching the sea at Valdez. Automobile roads traverse all these routes, except that of the Susitna River where it flows westward from the basin. It can be seen that all of the routes from the eastern part of the Gulf of Alaska to the Interior must pass through the Copper River Plateau at some place or another.

West of the mouth of the Copper River lies Prince William Sound, dotted with islands. The Kenai Peninsula, mountainous on the east and a lowland on the west, is located next along the coast. The Peninsula points southwesterly toward Kodiak Island, which seems to be a seaward continuation of the Peninsula. Shelikof Strait, separating Kodiak Island from the Alaska Peninsula, leads into Cook Inlet, a large body of water penetrating inland west of Kenai Peninsula. The Matanuska River flows into the Inlet from the east and the Susitna from the north. The Susitna, occupying in its lower and middle reaches a broad flat valley, has many branches. These head well up in the ranges, in passes that lead into the Copper, Tanana, Kuskokwim, and Cook Inlet drainages.

The eastern branches of the Susitna head around Mt. Hess and flow for part of their courses through the western part of the Copper River plateau. To the north, the Susitna drainage leads through Broad Pass to the Nenana River valley, the route of the Alaska Railroad. To the west, several passes lead to the Kuskokwim basin; formerly they were used for dog team travel; now they provide low altitude routes for airplanes.

Near the base of the Alaska Peninsula are several large lakes, among them Clark, Iliamna, Naknek, and Becharof. They all drain west to Bristol Bay.

The western end of the Pacific Mountain System is the Alaska Peninsula and its extension westward as the Aleutian Islands. The backbone of the Peninsula and of the island chain is the Aleutian Range. This feature, which separates the north Pacific from the Bering Sea, has a different curvature than does the System farther east. There the axis of the range is convex northward; in the Alaska Peninsula and Aleutian Islands the axis curves with the convex side to the south. From the base of the peninsula to the tip of the chain the distance exceeds 1500 miles.

Central Lowland and Plateau Region

The second of the broad physiographic provinces of Alaska is the Central Lowland and Plateau Region. Separated from the southern coast by the mountains of the Pacific Mountain System, most of the province enjoys a continental climate, with extremes of warmth in summer and cold in winter. Only the coastal strip, narrow in the south and widening northward, has an Arctic climate.

Although much of the province consists of rolling hills, some high enough to be called mountains, there are also great areas of lowlands, referred to as "flats". These flats comprise certain stretches of the valleys of the major streams, in one place almost one hundred miles wide, and the coastal plains near the mouths of the streams. The origin of some of the inland flats is still a mystery, although structural downwarping must surely have occurred, for the bedrock in places is below sea level and covered by a great thickness of river gravel, sands, and silts. Almost all of the major rivers contain such flats, which they enter and leave by steep walled valleys.

The Central Plateau Region is difficult to separate from the bounding mountain systems, especially on the north. Here, and also in the southwestern part of the province, the central province merges with the mountains by a gradual ascent. In many places, however, the transition is surprisingly sharp, leaving no doubt as to where the lowlands leave off and the mountains begin.

On the east, where the province crosses the Canadian border, it consists of a plateau with peaks as high as 6300 feet, bounded on the south by the valley of the Tanana and on the north by the Porcupine River. Through the northern portion of this plateau, the Yukon River, flowing northwest, has cut a deep, steep-walled valley. The upland between the Yukon and the Tanana is known as the "Yukon-Tanana Plateau" and in general decreases in height from west to east. Two minor units in the north central part of the plateau are called the White Mountains and the Crazy Mountains.

The uplands extend into Canada to the west beyond the interstream area of the Yukon-Tanana Plateau. North, between the Yukon and the Koyukuk, the uplands are known as the Ray Mountains, and farther west, as the Kokrline Hills. North of the Ray Mountains and still east of the Koyukuk, the transition to the Brooks Range is difficult to delineate - somewhere north of the Arctic Circle is probably as closely as it can be defined.

West of the Koyukuk, in the latitude of the Arctic Circle, the Zane Hills and the Lockwood Hills likewise provide a gradual transition to the Brooks Range. The upland then continues westerly to Seward Peninsula, where its average height increases; and southwesterly on the northwest side of the Yukon, until it terminates against the large flat near the mouth of the river. The plateau on Seward Peninsula is divided into several minor mountain units, among them the Darby Mountains in the southeast, the Bendeleben Mountains in the central portion, the Kigluaik Mountains in the southwest, and the York Mountains in the west.

The central highland extends in a southwesterly direction from the Yukon-Tanana Plateau as the Kuskokwim Mountains. The southern end of the range is known as the Kilbuck Mountains, while farther north are the Russian Mountains and the Beaver Mountains. The Kaiyuh Mountains form a separate unit between the Innoko and the Yukon Rivers.

The drainage of the Central Plateau Province empties into the Bering Sea. The largest stream in the area, the fifth largest on the North American Continent, is the Yukon. Heading in Canada behind the Coast Mountains of British Columbia and Southeastern Alaska, the river makes a great circuit northwesterly, westerly, and southwesterly, making its bend from northwest to southwest at Fort Yukon on the Arctic Circle.

After crossing the Alaska border near Eagle, the Yukon flows for about 100 miles in a relatively narrow valley through the Yukon-Tanana Plateau. Near Circle the river flows into the largest of the inland flats, known as the Yukon Flats, 100 miles across at its widest part and almost 200 miles long. These flats are a seemingly endless expanse of muddy sloughs, oxbow lakes, and boggy stream scars. Also flowing into this basin are the Porcupine from the northeast and the Christian and Chandalar rivers from the north. To the north the flats end against the Brooks Range; to the south against the Yukon-Tanana Plateau. As the Yukon swings southwest, it encounters the northern edge of the Yukon-Tanana Plateau and flows through it in a steep-walled valley called the Ramparts. For 120 miles the river continues through the hills to where it is joined from the south by its longest tributary, the Tanana. Strictly speaking, the Ramparts do not traverse the Yukon-Tanana Plateau but divide the plateau on the southeast from the Ray Mountains on the northwest.

From Tanana, at the juncture of the Yukon and the Tanana, the Yukon flows through a valley perhaps ten to fifteen miles wide. Except for a ten mile stretch near Ruby, the Yukon continues to flow through a wide valley, always hugging the right (north or west) bank. Between 158° and 160° west longitude the river flows south almost 260 miles. From 160° west longitude to the sea, it flows along the north side of a huge delta which stretches south with unbroken flatness to the Kuskokwim Valley. The Yukon flows into Norton Sound through several channels.

The Tanana River, chief tributary of the Yukon from the south, actually heads as a small stream called Mirror Creek at the International Boundary. From the confluence of Mirror Creek and the Chisana River, the Tanana flows northwesterly through a series of basins or flats which alternate with short stretches where the valley is relatively narrow. Below the Little Delta River, the Tanana flows against the north side of a large flat, second in size only to the Yukon Flats.

Another major tributary of the Yukon, flowing southwest from the Brooks Range is the Koyukuk. This river drains a large segment of the south slope of the range and for the upper 100 miles or so it and its various tributaries are typical mountain streams. Near Bettles, however, the Koyukuk enters large flats - the flats of the middle Koyukuk. The river traverses the flats, hugging the west side, and again passes into a narrow valley to emerge near 66° north latitude in another flat, through which it makes its way about 90 airline miles to the Yukon.

A striking feature of the Central Province is the low flat divide between the Tanana Valley and the upper drainage of the Kuskokwim. The upper Kuskokwim flows through a wide flat (again hugging the northwest bank), and with the Tanana Flats, makes a lowland extending parallel and adjacent to the north side of the Alaska Range for over 350 miles. From the vicinity of McGrath, however, the Kuskokwim cuts through the Kuskokwim Mountains in a well defined channel for an airline distance of over 200 miles. From Aniak to the sea, 140 miles airline distance, the river flows through the large flat occupied farther north by the Yukon.

The southern tributaries of the upper Kuskokwim drain the Alaska Range; the tributaries of the middle river drain from a foothill group called the Taylor Mountains. A lowland between the

Aleutian Range on the southeast and the Taylor Mountains and Kilbuck Mountains on the northwest is occupied by the Nushagak River and its tributaries. This river flows into Bristol Bay.

A feature of the drainage of the Interior Province, which is immediately apparent upon looking at a map, is that the major streams trend either northwest-southeast or southwest-northeast. Thus, the Yukon flows northwest to the mouth of the Porcupine, which flows into the Yukon from the northeast. From the mouth of the Porcupine to the delta, the Yukon trends southwest; it skirts the north side of the delta in a northwest direction. The Tanana flows northwest; the Koyukuk southwest; and the Kuskokwim and Nushagak, southwest.

The Interior Lowland and Plateau Province contain the following regions: Kuskokwim, Seward Peninsula, and parts of the Bristol Bay and Yukon River.

Brooks Range

The third physiographic province is that called by Alfred Brooks the Arctic Mountain System, now known as the Brooks Range. The geography of this province is much simpler than that of the two already considered. The province may be considered the northwestern extension of the Rocky Mountains, stretching entirely across the northern part of Alaska from east to west, a distance of over 600 miles. The mountains enter Alaska after bending sharply to the west in Canada. The axis of the range in the east curves with its convex side north, but the main part of the range, to the west, curves gently in the opposite direction. The separate mountain units are, from east to west, the British Mountains, the Ramanzof Mountains (with the Davidson Mountains south of them), the Franklin Mountains, the Philip Smith Mountains, and the Endicott Mountains. The western end of the range is split into several units. The Schwatka Mountains lie between the headwaters of the Noatak and the Kobuk; farther west the area between the Noatak and the Kobuk is known as the Baird Mountains. North of the Noatak are the DeLong Mountains; between the Kobuk and the Selawik are the Waring Mountains.

The drainage of the Brooks Range flows southward to the Yukon, westward to Kotzebue Sound, and northward to the Arctic Ocean. In the east, the Porcupine is considered to separate the Brooks Range Province from the Interior. Into the Porcupine, from the north, flow the Coleen and the Sheenjek. Next, to the west, flowing into the Yukon, is the Christian, then the branches of the Chandalar, East, Middle, and North Forks. The Chandalar enters the Yukon Flats from the northwest. The next drainage system to the west is the Koyukuk, which in general flows southwest. This river also has many branches; from east to west the most important are the South Fork, Middle Fork, North Fork, John, and the Alatna.

Three westward flowing streams, more or less parallel, drain to Kotzebue Sound. From north to south they are the Noatak, the Kobuk, and the Selawik, although the Selawik drains an area that might just as well be grouped with the Interior Province.

To the north the province is drained by rivers which flow to the sea, analogous to those in the south flowing to the Yukon. Those in the east flow in general straight north out of the mountains. They are, from the east, the Kongakut, the Hulahula, the Canning, and the Sagavanirktok. The western portion of the Arctic drainage flows out through the Colville, which flows generally eastward through the province to a point near the center of its east-west dimension, from where it gradually swings north. The most important of its tributaries are the Itkillik, Anakutuk, Chandler, Killik, and the Etivluk. A few small streams, among them the Kakalik and the Kukpowruk, drain north in the western end of the Range.

The Brooks Range Province includes portions of the Yukon River Region, the Northern Alaska Region, and the Northwestern Alaska Region.

Arctic Slope

The last of the four major provinces of Alaska is the Arctic Slope. This province lies between the Brooks Range on the south and the Arctic Ocean on the north. It is only a few miles wide near the Canadian border but gradually widens to almost 150 miles in the longitude of Barrow. West of Barrow the coast line swings south, so that the Arctic Slope gradually decreases in width; near Point Lay, where the mountains of the Brooks Range stand at the sea, the Arctic Slope province dies out.

The province is very simple geographically and physiographically. From the mountains on the south the elevation gradually decreases half way to the coast from where a flat, lake-dotted plain continues to the sea. Two geomorphic units comprise the province. Near the mountains it is a gently rolling plateau, gradually decreasing in altitude northward. The northern flat is a coastal plain.

The drainage of the province is by the same north-flowing streams draining the mountains already named, except that in the west, north of the Colville drainage, are the Ikpikpuk, the Topagoruk, the Meade, the Nigisaktuvik, and several smaller streams.

The province includes a portion of the Northern Alaska Region.

CHIEF TRANSPORTATION AND COMMUNICATION ROUTES

Basically, there are three approaches to Alaska, although many variations locally are encountered. These three approaches are by ship from the West Coast of the United States or Canada, by the Alaska Highway, or by air direct from the United States or Canada.

Ocean freight from Seattle or San Francisco moves direct to most of the seacoast towns in Alaska and where lighterage can be provided, to almost any point on the coast where freight may be needed. Southeastern Alaska and the large towns on the Gulf of Alaska have regular and frequent service; the Aleutian Islands and Bering Sea points have less frequent trips, and only during the summer season. One ship a year goes on to Kotzebue Sound and the Arctic Ocean. There is, at present, no passenger service on the ships except for special excursions.

In Southeastern Alaska, small boats haul light freight from the towns to isolated points, and around almost any seacoast town, boats may be hired for freighting. On Seward Peninsula and farther north, Eskimos and their skin boats may be hired.

Formerly, river boat travel was the lifeblood of the Interior. Today river boat travel is still an important means of transportation, although its all-importance has been taken away by the railroad, the automobile, the tractor, and the airplane. Freight moves from Skagway to Whitehorse by narrow gauge railway, thence to Dawson by river boat. Independent freighters haul under charter from Dawson to Alaskan River points.

From Bethel at the mouth of the Kuskokwim, freight moves as far as Medfra. St. Michael, in Norton Sound, is the trans-shipment point for lower Yukon freight. From St. Michael, boats ascend to Marshall. River boat freight service is also available on the Kobuk from Kotzebue. With the development of the Copper deposit on Ruby Creek near Shungnak, river transportation in this area will take on increased importance.

Most of the river freight of Alaska moves through Nenana. Freight reaches Nenana from the United States proper by rail from Whittier or Seward, thence moves on to Fairbanks by rail or down the river by boat. Large boats running on a regular schedule descend the Yukon so far as Marshall and ascend to Fort Yukon or Circle. Several independent river freighters operate from Fairbanks and Nenana, going wherever business justifies. These freighters service all Tanana and Yukon River points from Nenana to Marshall and up to Fort Yukon. Small boats also operate from Circle down to Fort Yukon and up to Coal Creek as well as on to Porcupine. The Iditarod and Innoko are served by boat, and when justified, the Koyukuk as far as Bettles.

Heavy freight for the Interior goes to Nenana or Fairbanks by rail or truck and is distributed from there by truck, plane, or boat. There are three truck approaches to the Interior, the most important of which is that from Valdez via the Richardson Highway. Another route leads from Seward, where vans are unloaded from barges, through Anchorage and thence to the Interior via the Glenn and Richardson highways. The third route leads direct from the continental United States via the Alaska Highway.

The road system of Alaska still is almost wholly confined to the area south of the Yukon and east of the Alaska Railroad. From Valdez on Prince William Sound, the Richardson reaches 370 miles to Fairbanks. Ninety nine miles from Fairbanks the Richardson is joined by the Alaska Highway. From the Junction at Big Delta to the Canadian Boundary the Alaska Highway follows the Tanana Valley for 208 miles.

Between Seward and Anchorage, a road 130 miles long parallels the railroad. The Sterling Highway leaves this road thirty eight miles from Seward and extends to Homer on Katchemak Bay, a distance of 148 miles. An eighteen mile road connects the Seward-Anchorage road with Hape, and a short road leads from the Sterling Highway to Kenai and Solomafot.

From Anchorage to Glenallen on the Richardson, the Glenn Highway is 189 miles long. Short roads connect Palmer on this highway with the Willow Creek mining district, Wasilla, Houston, and Knik. A side road from the Richardson leads to Chitina at the juncture of the Chitina and Copper Rivers. This road, now thirty nine miles long, is expected to connect with a road along the old Copper River and Northwestern Railroad bed to Cordova. The road has already been extended a short distance from Cordova.

From Gakona on the Richardson Highway to Tok Junction on the Alaska Highway, the Tok Cutoff extends for 132 miles. A road leads from Slana on the Tok Cutoff to Nabesna, a distance of about forty miles.

From Fairbanks the Steese Highway extends 162 miles to Circle on the Yukon. The Elliot Highway leaves the Steese at Fox, mile 11, and extends to Livengood, seventy miles away; this road has been extended to Manley Hot Springs and will eventually go to Nome. Short roads connect the Steese Highway with Fish Creek and Fairbanks Creek near Fairbanks and with Circle Hot Springs and the creeks of the district near the Circle end of the road. A short road leads from Fairbanks to the University of Alaska, at College, and on to Ester; this road has been extended to Nenana and will go to McKinley Park.

The Taylor Highway joins the Alaska Highway at Tetlin Junction, 221 miles from Fairbanks. The road traverses the Fortymile district, a distance of about 120 miles to the Canadian border, and thence on to Dawson and Whitehorse. A road sixty seven miles long extends from Boundary, on the Taylor Highway, to Eagle.

The Haines Road extends from tidewater at Haines in Southeastern Alaska 154 miles to join

the Alaska Highway at Haines Junction, west of Whitehorse in Canada.

About forty miles of roads extend out from Juneau.

From the Alaska Railroad, roads lead from McKinley Park Station ninety one miles into the Kantishna, from Talkeetna about fifty miles west into the Yentna district, and from Ferry about twenty five miles east into the Bonniel. The Mt. McKinley road connects with the Denali Highway, connecting Cantwell on the Railroad with Paxson on the Richardson Highway.

The other roads in Alaska are short ones servicing mining districts from river or ocean supply points. From Manley Hot Springs, roads run twelve miles to Tofty and twenty miles to Eureka. A road extends south from Ruby on the Yukon River to Poorman and from Candle Landing on the Kuskokwim to Takotna and Ophir. On Seward Peninsula, a narrow gauge rail line, suitable for gas cars, runs from Nome to Bunker Hill, and a truck road continues to Taylor. A road also runs from Nome eastward along the coast to Solomon, Casadapaga, and Council.

Almost every town or camp in Alaska now has an airfield of some kind. Regular flights between Seattle and Fairbanks are made daily, with stops at Annette Island, Juneau, and Whitehorse several times weekly. The flight also continues to Nome on specified days. Regular daily flights also connect the continental United States with Anchorage. Flights may originate almost anywhere in Alaska, bound for almost anywhere, but the bulk of the flying, especially freighting, falls into definite patterns determined by economy. Thus in Southeastern Alaska, flights originate in the larger towns and are made principally by amphibious planes. Fairbanks serves the Interior, south to the Alaska Range, east to the Fortymile, west to the upper Kuskokwim and Nome, north to the eastern Brooks Range, and on to Barrow. Flights originating in Anchorage serve the south side of the Brooks Range, the Kuskokwim, the Aleutians, and the Bering Sea. Nome air traffic serves the Seward Peninsula and Lower Kobuk. Many smaller supply centers exist at Cordova, Valdez, Kodiak, and Bethel, and many villages support one or two small planes.

Communication between Alaska and the Outside is by ocean mail, air mail, submarine cable, landline, and radio. Radio, telegraph, and long distance telephone services are operated by a branch of the U. S. Signal Corps, known as the "Alaska Communication System", or simply as "A.C.S.". Radio communication between the larger towns where A.C.S. stations are located and small towns and camps is via small radio stations owned and operated by individuals or by the Alaska Native Service. In addition, several other government agencies maintain radio networks.

Mail moves to the small settlements of Alaska by a method determined by competitive bidding. Today almost all such mail, even parcel post, goes by air, except where road or railroad transportation is available.

The principal cities of Alaska are Ketchikan and Juneau in Southeastern Alaska, Anchorage on Cook Inlet, Fairbanks in the Interior, and Nome on the Seward Peninsula.

References

- Brooks, Alfred H., 1953, *Blazing Alaska's Trails*: University of Alaska and Arctic Institute
 Ransome, Alfred L., and Kerns, William H., *Names and Definitions of Regions, Districts, and Subdistricts in Alaska*: U. S. Bureau of Mines, I.C. 7679
 Williams, Howel, 1958, *Landscapes of Alaska*: University of California Press, Berkeley and Los Angeles



Appendix I

SOURCES OF INFORMATION AND AID TO PROSPECTORS

Several government agencies provide information and direct aid to prospectors. An understanding of their functions will increase the prospector's efficiency.

The United States Geological Survey

This agency, a permanent Federal organization founded in 1879, studies the geology and topography of the country and makes its results available in the form of maps and books which are sold to the public at nominal prices. In the course of its work, it discovers much information which is of more or less direct value to prospectors. The U. S. Geological Survey also provides direct aid in the identification of samples or in calling attention to specific features which might be observed in conducting a general study. It also examines reported occurrences of radioactive or other minerals which the government desires to be developed. Its name is often abbreviated to U. S. G. S., or simply "the Survey".

The U. S. Geological Survey is divided into a Geology Division, a Conservation Division, a Water Resources Division, and a Topographic Division. Under the Geology Division, the Alaskan Geology Branch is concerned with Alaskan Geology. The Conservation Division handles problems of leasing minerals, land classification, and power resources. The Water Resources Division investigates water supply. The Topographic Division (Alaska headquarters in Denver) is in the Rocky Mountain Region and is charged with the topographic mapping of Alaska.

From 1880, when the Geological Survey issued its first paper, until 1901, the reports of the U. S. Geological Survey were made a part of an Annual Report of the Director. About 1891 descriptions of investigations in Alaska began to be included as parts of these reports. Beginning with the Twenty Third Report in 1902, the technical papers of the Survey began to be published separately as Bulletins, Professional Papers, Water Supply Papers, and Mineral Resources (the publishing of Mineral Resources was transferred to the Bureau of Mines in 1925). Monographs, contributions to general geological knowledge, were published until 1929. Folios of the Geologic Atlas of the United States, map-sized publications describing particular sections of the country, also have been supplanted by different types of reports. The Geologic Quadrangle Maps with brief geological descriptions correspond most closely to these. Circulars are small, usually mimeographed reports, issued free on request. There are no folios or monographs applying to Alaska. By far the greatest amount of information of help to prospectors is found in the Bulletins. Each Bulletin describing an area is accompanied by a topographic map and a geologic map, and these are, for most sections of Alaska, the only geologic maps available.

From 1904 to 1942 the Survey published yearly resumés of mining activities in Alaska, entitled Mineral Industry in Alaska, in addition to descriptions of the geology and resources of individual areas. Since 1942 Mineral Industry in Alaska has been published by the U. S. Bureau of Mines, but the U. S. Geological Survey continues to issue bulletins on mineral deposits and descriptions of geology in Alaska. In addition to the regular series, several special publications have been issued. A few early reports on Alaska corresponding to bulletins are included among these.

The List of Publications of the Geological Survey is issued every five years, and supplements are issued periodically in the intervening years. A Finding List of Commodities and of Areas Listed by Quadrangles and Index Map of Alaska is issued periodically. These are invaluable in using the U. S. Geological Survey literature on Alaska. Geologic and Water-Supply Reports on Alaska is also a valuable guide to Survey literature.

All of the publications, except Circulars, are ordered from the Superintendent of Documents, Washington 25, D.C. Payment must be made in advance by postal or express money order or in cash at the sender's risk. Rather complete files of Survey publications dealing with Alaska may be examined at the U. S. Geological Survey offices at Anchorage, College, or Juneau; at the Division of Mines and Minerals offices in Juneau, Anchorage, College, or Nome; or at the University of Alaska Library, or at the Library of the College of Earth Sciences and Mineral Industry. Special unpublished reports called Open File Reports can be examined at the Survey offices. They may be reproduced by any interested person at his own expense.

U. S. Geological Survey maps of Alaska are of several types. Four base maps of Alaska are issued, ranging from Map B, issued in two parts, which covers a large area on a wall, through Map E, also a wall map, to Map A, a large desk-sized map and Map C, a small planimetric map suitable for locating certain gross features.

Alaska is now completely mapped at a scale of 1:250,000 (about 1"=4 miles) in the Alaska Topographic Series, and certain areas are mapped at scales of 1:62,500 and 1:63,360 (1"=1 mile). Index maps showing areas covered by topographic and geologic maps may be obtained free from the U. S. Geological Survey, Washington 25, D.C.

The United States Bureau of Mines

The Bureau of Mines, originally created to promote safety and provide rescue facilities in coal mining, is a Federal Agency which conducts research into problems in any way related to mining and makes its re-

sults known through the sale of books and pamphlets. It also selects a few properties each year, the development of which does not present an attractive investment to private capital, and performs exploration work, often actually drilling and trenching if it appears that this will help get into production a property which will be of value to the national mineral economy. No charge is made for this work. If a prospector believes that he has a deposit, the development of which would be in the national interest, he should write to the Assistant Regional Director for Alaska, United States Bureau of Mines, Juneau, Alaska. The Bureau has a mineral dressing research laboratory at Juneau for the purpose of discovering ore dressing techniques applicable to Alaskan deposits.

A Bureau of Mines Safety Engineer is stationed at Anchorage with a special railway car fitted as a mobile mine-rescue unit. He proceeds immediately to any coal mine at which rescue work may be needed, inspects mines for safety conditions, and provides instruction in first aid and mine rescue technique.

The publications of the United States Bureau of Mines fall into two classifications: Those of permanent value which are printed, and those of transitory or local value, which are mimeographed or otherwise processed. The printed material is sold by the Superintendent of Documents, Washington 25, D.C., and the processed papers are distributed free (one copy to a person) on request to the Publications Distribution Section, Bureau of Mines, 4800 Forbes St., Pittsburgh 13, Pennsylvania.

The printed publications include *Bulletins*, which describe major research; *Technical Papers*, preliminary reports on major projects; *Economic Papers*, summaries and analyses of the economic side of the mining industry; *Miners' Circulars*, publications describing safety measures; *Mineral Resources* statistics on production and consumption of minerals; *Minerals Yearbook*, annual statistics of mining; *Handbook*, guides to recommended procedures; *Monographs*, detailed results of special projects; *Schedules*, describing tests of equipment; *Data Books*, analyses of coal; and the *Annual Report of the Director* (free; order from the Distribution Section). *Technical Papers*, *Economic Papers*, and *Miners Circulars* since 1949 have been issued as *Bulletins*.

The mimeographed or otherwise processed publications include *Reports of Investigations*, describing main points of minor investigations or parts of major investigations; *Information Circulars*, providing concise descriptions and information on almost any phase of mining; *Periodical Reports*, statistics on a number of mineral commodities, issued weekly, monthly, or quarterly; *Mineral Market Reports*, issued annually, containing advance information which will later go into the *Minerals Yearbook*; and *Injury Statistics*. Certain special work conducted in cooperation with other organizations is usually described by the cooperating agency.

Certain libraries are designated by law as depositories for Bureau of Mines Publications. The University of Alaska gets all *Information Circulars* and *Reports of Investigations* as well as selected printed books. The Territorial Historical Library and Museum at Juneau receives *Information Circulars* and *Reports of Investigations*.

The State Division of Mines and Minerals

This was formerly the Territorial Department of Mines and is now a state agency which aids individual miners or prospectors through furnishing free assays and examinations of properties. It also conducts investigations of general value to the mining industry and enforces safety rules in metal mines. The name is usually shortened to D. M. M.

The Division maintains field offices in Juneau (the headquarters), Anchorage, College, and Nome. At each of these offices an engineer is stationed who provides engineering services to prospectors who may need them for short periods. The Division also maintains assay offices in Ketchikan, Anchorage, College, and Nome to which prospectors may send samples for identification or assaying free of charge. There is a small charge to non-residents. There are also a Coal Mine Inspector, a petroleum engineer, and a petroleum geologist at Anchorage. The Director and clerical and statistical personnel at Juneau complete the staff. Part of the duties of the engineers is to make examinations of properties for individuals. Reports on such work are confidential, but certain reports, pamphlets, descriptions, and maps of general value may be examined by the public at the offices. Some information is published and copies of pamphlets still in print can be obtained from the Juneau office. A *Bulletin* is sent free each month on request. This contains current news on mining operations, laws, and other items of interest to the industry, including the latest metal prices from the current *Engineering and Mining Journal*.

The engineers of the Division of Mines and Minerals may also have direct or indirect personal knowledge of an area which might be of value to prospectors and which can be obtained by writing to or talking with them.

The Division is authorized by law to provide financial aid to qualified prospectors. If the prospecting venture is considered worthy of help, the Division can reimburse the prospector for certain items of expense. In return, the prospector must furnish information obtained in the work which is kept confidential for a period of time. Details can be obtained from the Division.

Atomic Energy Commission

The Atomic Energy Commission is a Federal agency controlling atomic energy. There are no representatives of the Commission in Alaska; investigation of deposits is conducted by the U.S. Geological Survey.

Deposits of uranium are acquired in the same way as those of other minerals, except that the Government retains the right to seize and mine them if the owner refuses to mine or to sell them himself. A special license is required to transport, buy, or sell uranium ore, and this must be obtained from the Commission, not from the U. S. Geological Survey.

The price paid by the Commission for uranium ore is affected by numerous allowances and bonuses and depends upon the grade, amount, distance from market, and other factors. Anyone who believes that he has a uranium prospect should ask one of the agencies already described for information and aid.

The commission issues numerous reports and publications (See reference at end of Chapter 15).

Lending Agencies

Until a short time ago, the Reconstruction Finance Corporation (RFC), a lending agency of the Government, made loans on qualified mining projects. This agency is no longer existent, and most of the loans on operations in Alaska have been paid off. However, other agencies, set up to promote the mining of strategic minerals have from time to time supplanted it. For a time, Defense Minerals Exploration Agency made loans under very favorable terms to the industry. At present the Office of Mineral Exploration (OME) makes such loans.

Anyone wishing to determine the extent of Government aid at present should write to the Assistant Director for Alaska, U. S. Bureau of Mines, Juneau, Alaska.

The Bureau of Land Management

This Bureau, long known as the Land Office, administers the public lands. Among the functions of this bureau are classifications of public lands, registering of homestead entries, issuing of land patents of all types, and keeping track of the great number and constantly changing withdrawals of land from the public domain. The headquarters office for Alaska is in Juneau. (The First District office is also located there). The Third District office is located at Anchorage and the office for the Second and Fourth Districts is at Fairbanks.

College of Earth Sciences and Mineral Industry
(formerly School of Mines)

The University of Alaska College of Earth Sciences and Mineral Industry provides professional education in mining, metallurgy, and geology. A short course in mining and prospecting is presented each year by the Mining Extension Department in many Alaskan towns and cities where the demand exists. This course gives the fundamentals of general geology, mineralogy, prospecting, and mining. It is given in the winter. A similar course is given at the University each winter, known simply as the Short Course in Mining.

In addition to these courses, collections of minerals and rocks are available for examination by prospectors, and many books and other publications may be consulted at the University library.

Others

The two agencies with which the prospector may come in contact are the United States Coast and Geodetic Survey (abbreviated Coast Survey) and the Alaska Resources and Development Board. The Coast and Geodetic Survey charts coasts and large areas of the country and studies the earth's magnetism and earthquakes. The prospector may have occasion to use Coast Survey maps or to obtain magnetic data from one of its Alaskan stations. The Alaska Resources and Development Board is authorized to "foster the industrial, business, and vocational development of Alaska". It has conducted studies of the opportunities for development, acted as a clearing house for information, and conducted prospective industries. The prospector could easily come in contact with an organization with such a broad scope.

The Mining Magazines are current sources of information on prospecting and mining and should be read whenever the opportunity arises. Most of these contain the latest metal prices.

If aerial photographs of a prospecting area are available, they should be obtained. Information as to, first, are they in existence, and, second, can they be supplied, can be obtained from the U.S. Geological Survey or Photographic Records and Services Division, Office of Research and Liaison, Aeronautical Chart and Information Center, Washington 25, D.C.

Government publications which are out of print may be obtained from second hand booksellers specializing in geological literature. Names and addresses of some of these may be obtained from the Division of Mines and Minerals office in Juneau, as can names of smelters, mine and mill supply houses, and drill manufacturers.

Appendix II

WEIGHTS, MEASURES, AND SIZES

Weights

Avoirdupois (Awdp.)

27 11/32 grains	1 dram (dr.)	
16 drams	1 ounce (oz.)	
16 ounces	1 pound (lb.) awdp.	1.2152 troy
100 pounds	1 hundredweight (cwt.)	
20 hundredweight	1 ton	
112 pounds	1 gross weight or long hundredweight	
20 long hundredweights	1 gross ton or long ton	2240 lbs.

Troy (Tr.)

(The grain is the same as in avoirdupois).

24 grains	1 pennyweight (dwt.)	
20 pennyweights	1 ounce troy	480 grains
12 ounces tr.	1 pound (lb.) troy	

Metric

10 milligrams (mg.)	1 centigram (cg.)
10 centigrams	1 decigram (dg.)
10 decigrams	1 gram (g.)
10 grams	1 dekagram (dkg.)
10 dekagrams	1 hectogram (hg.)
10 hectograms	1 kilogram (kg.)
1000 kilograms	1 metric ton (t.)

The following approximate weights may be helpful.

1 copper cent	47 grains	2.0 dwt.
1 nickel	79 grains	3.3 dwt.
1 dime	39 grains	1.6 dwt.
1 quarter	95 grains	4.0 dwt.
1 fifty cent piece	192 grains	8.0 dwt.
1 silver dollar	412 grains	17.0 dwt.

Gold

1 lb. awdp.	1.2153 lb. troy
1 lb. troy	0.8229 lb. awdp.
175 oz. troy	192 oz. awdp.

Gold at \$30 per ounce tr. is worth:

\$1.50 per dwt.
\$0.0625 per grain
\$437 per lb. awdp.

Very fine gold (flour gold) may require several hundred colors to make one cent. A piece so small as to be worth 1¢ will ring a pan when dropped into it.

Gravel

One pan (heaping)	1/10 to 1/7 cu. ft. of gravel
One cu. yd. of gravel weighs about	3000 lbs.
One man can pan	1/2 to 1 cu. yds. of gravel per day.
One man can shovel up to	7 cu. yds. of gravel per day.

Linear Measurements

English

12 inches (in.)	1 foot (ft.)	
3 feet	1 yard (yd.)	
5 1/2 yards	1 rod (rd.)	16 1/2 feet
5280 feet	1 mile(mi.)	
1 claimlength (placer)	1/4 mile	1320 feet
1 boxlength	12 feet	
1 chain	66 ft.	
80 chains	1 mile	
100 links	1 chain	

Metric

10 millimeters (mm.)	1 centimeter (cm.)	
10 centimeters	1 decimeter (dm.)	
10 decimeters	1 meter (m.)	100 cm.
1000 meters	1 kilometer (km.)	

Areas

English

144 square inches (sq.in.) or (in. ²)	1 square foot	
9 square feet	1 square yard	
272 1/4 square feet	1 square rod	
160 square rods	1 acre	4840 square yards 43,560 square feet
1 acre	43,560 square feet	
640 acres	1 square mile	
1 section	1 mile square	
1 township	36 miles square	36 square miles
1 boxlength	144 square feet	usually 12 ft. x 12 ft.
1 bedrock foot	1 square foot of bedrock (regardless of depth of overburden)	

Metric

100 square millimeters (sq.mm.)	1 square centimeter	
100 square meters	1 are (a.)	
100 ares	1 hectare (ha.)	10,000 sq. meters
100 hectares	1 square kilometer	

Cubic Measure

English

1728 cubic inches (cu.in.)	1 cu. foot	
27 cubic feet	1 cu. yard	
1 cubic yard	1 bedrock foot if it has 27 feet of unconsolidated material above it.	

Metric

1000 cubic millimeters	1 cubic centimeter (cc. or cm. ³)
1000 cubic centimeters	1 cubic decimeter
1000 cubic decimeters	1 cubic meter

Liquid Measure

English

4 gills	1 pint (pt.)	28.875 cu. inches
2 pints	1 quart (qt.)	
4 quarts	1 gallon (gal.)	231 cu. inches
1 cu. foot	7 1/2 gallons (approx.)	
1 miner's inch	1.5 cu. ft. per minute	11.25 gallons per minute
40 miner's inches	1 cu. ft. per second	7 1/2 gal./sec.
1 acre ft. of water	325,850 gallons	
1,000,000 gal. per day	695 gallons per minute	
1 sluichead	enough water to sluice gravel, depends on sluice size and grade; approximately 100 miner's inches per foot of width	

Metric

10 milliliters (ml.)	1 centiliter (cl.)
10 centiliters	1 deciliter (dl.)
10 deciliters	1 liter (l.)
1000 liters	1 kiloliter (kl.)

SIZES OF CHURN DRILL TOOLS AND CASINGS (AFTER PEELE)

Drive Pipe

Nominal Size, in.	Inside Diam. in.	Cross-Sec. Area		Volume per Ft. depth		Weight per Ft., lb.
		Sq. in.	Sq. ft.	cu. in.	cu. ft.	
4	3.826	11.50	0.080	137.96	0.08	14.98
5	4.813	18.19	0.126	218.32	0.13	20.78
6	5.761	26.07	0.181	312.80	0.18	28.57
8	7.625	45.66	0.317	547.96	0.32	43.39

Round Drill Stems

Diameter in.	Weight per ft., lb.	Diameter in.	Weight per ft., lb.
3 1/8	26.08	4.25	48.23
3.25	28.21	4.5	54.07
3.5	32.71	4.75	60.25
4	42.73	5.0	66.76

Drive Shoes

Cutting edge diam., in.	Cross Sectional Area		Vol. per depth		Ft. driven to cut 1 cu. yd.
	Sq. in.	Sq. ft.	Cu. in.	Cu. ft.	
5.25	21.6475	0.15	259.77	0.15	179.6
6.5	33.1832	0.23	398.20	0.23	177.1
7.5	44.1788	0.31	530.14	0.31	88.0
9.75	74.6621	0.52	895.94	0.52	52.1

Core Rise

Pipe, inches	Shoe Inches	Core Rise per ft. depth
4	5.25	22.6 in.
5	6.5	21.9
6	7.5	20.3
8	9.75	19.6

Appendix III

SHORT GLOSSARY OF ALASKAN TERMS

(Partly from the Rand McNally Guide to Alaska and the Yukon, 1922)

Note: No attempt is made here to present a comprehensive glossary of mining or geological terms. In large part Alaskan colloquial and specialized mining terms are given. See Bibliography for glossaries of mining and geology.

- Above**- Designates a placer claim upstream from the original or "discovery" claim on that creek.
- Basket sled**- Dog sled with high sides, forming a three-sided basket.
- Bedrock**- Solid rock underlying unconsolidated material. In placer prospecting and mining, means to reach bedrock, where the gold, if any, will be found.
- Bedrock drain**- Trench up a creek at a flatter gradient than the creek, which reaches bedrock at its upper drain.
- Bedrock feet (b.r.f.)**- Number of square feet of bedrock.
- Bedrock foot (b.r.f.)**- One square foot of bedrock.
- Bedrock pay**- Little used today. The custom of not paying hired men in a mine until the mine has produced or "reached bedrock".
- Below**- Designates a placer claim below or downstream from the original or "discovery" claim on that creek.
- Bench**- The sloping part of a valley beside a creek. Refers to a placer in that part of the valley not occupied by the present channel.
- Blaze**- Slash on tree to mark a trail.
- Bottom**- Packed part of a trail under fresh snow.
- Break trail**- To be first over a new trail in snow.
- Burn down**- To sink a hole in frozen ground by thawing the ground with direct fire.
- Cache**- Storehouse, often built on posts for protection from bears. To store something.
- Camp**- Site of a temporary tent home. A mining district. To live in a temporary tent home. To stop and make a temporary home.
- Cheechacko**- Newcomer to Alaska, tenderfoot. Produced outside of Alaska. (Little used today.)
- Cleanup**- The gold produced by a mine since the last time the gold was taken from the recovery apparatus.
- Clean up**- To recover the gold from sluices, plates, tables, etc.
- Creek**- A stream smaller than a river. As an adjective, refers to a placer near the center of a creek valley.
- Cut**- An excavation open to the air.
- Deep ground**- Placer ground in which depth to bedrock is a factor to be considered. (Comparative).
- Diggings**- Mineral deposit or mining camp, especially placer.
- Discovery**- The small amount of mineral that encourages a prospector to expend further effort on a property.
- Discovery claim**- The claim on a creek on which gold is first discovered. All other claims are numbered upstream (above) or downstream (below) from this one. Any claim on which mineral is first discovered in any area.
- Drain**- Trench to drain ground.
- Drawn out**- To lose a placer shaft or drift after striking unfrozen ground so that water comes in.
- Dry frost**- Frozen ground that does not contain an appreciable amount of water and can be picked or otherwise dug without thawing.
- Dust**- Fine gold.
- Fineness**- The proportion of pure gold in naturally occurring gold, expressed as parts per 1000. The difference between the fineness and 1000 is the amount of other mineral (principally) silver. Also applies to silver.
- Frost**- Frozen ground, whether seasonal or permanent. This is a prospector's term, not a geological one. Temperatures below freezing.
- Frozen ground**- Any frozen ground, usually permanently frozen.
- Frozen hole**- A drillhole or shaft in frozen ground.
- Glacier**- Slowly moving ice. (See Chapter 6.) As used commonly, although erroneously in Alaska, ice which builds up on the surface as a result of seeping water. Icing, aufeis. To become covered by an icing.
- Grizzly**- Spaced bars or holes that limit the size of fragments that can pass through.

- Ground**- Land containing mineral deposit; "good ground", "poor ground", "patented ground", etc.
- Ground sluice**- To mine a creek by allowing water to sweep away the finer gravel. The opening made by groundsluicing.
- Grubstake**- An amount of money sufficient to outfit a prospector. To furnish such an outfit. (Often the basis for a 50/50 split on any mineral deposit discovered by the prospector).
- Hardrock**- A lode mineral deposit.
- Hole**- Shaft.
- Ice bridge**- Winter river crossing made by pumping water onto ice surface to thicken it.
- Interior**- North of the Alaska Range.
- Limit**- In looking down a stream, the left limit is the left side and the right limit, the right side. Abbreviated L. L. and R. L.
- Lode**- Mineral deposit occurring in consolidated rock as distinguished from a placer deposit.
- Marginal**- Mining ground borderline between being rich enough to mine and too poor to mine.
- Mukluk**- Eskimo boots.
- Mush**- To drive dogs or walk.
- Native**- An Alaskan Indian or Eskimo. As an adjective, equipment or clothing produced by Natives. Sometimes for locally grown commodities.
- Niggerhead**- Tuft or clump of grass and roots growing in swamps and tundra.
- Nuggets**- Chunks of gold--distinguished from dust.
- On the money**- To be prospecting or mining on the paystreak or in a productive part of a lode.
- Outside**- The continental United States, so called originally because it was "outside" the Territory of Alaska.
- Overflow**- Water flowing on top of ice. (See Chapter Six for ice terms).
- Parka, Parky**- Slipover coat with hood.
- Pioneer**- Member of Pioneers of Alaska.
- Placer**- Mineral deposit in alluvial material.
- Poke**- Moosehide or leather bag for holding and transporting placer gold.
- Prospect**- To search for a mineral deposit. Mineral deposit before proved to be a mine. Small amount of mineral constituting a discovery.
- Pup**- Short creek.
- Quartz**- Mineral silica (SiO_2); mineral deposit in which gold occurs in quartz as a lode claim.
- Rawhide**- To drag on a rawhide instead of a sled.
- Riffles**- Obstructions in the bottom of a sluice-box to create turbulence.
- Roadhouse**- Small hotel or inn along a trail or in a village.
- Shallow Ground**- Placer ground of such depth to bedrock that depth is not a serious hindrance. (Comparative).
- Shelter Cabin**- Small cabin along trail for protection of travelers.
- Shoepac, Shoepack**- Boot with leather upper and rubber sole and lowers.
- Si washing**- To camp without shelter other than that provided by brush, etc.
- Skookum**- Strong, powerful, capable (sometimes).
- Sluice**- String of sluice boxes; to wash gold in a sluice box.
- Sluice box**- Box with riffles through which gravel is washed to recover gold.
- Sluice head**- Enough water to sluice.
- Snow boots**- Boots with leather or moosehide lowers and canvas uppers.
- Sourdough**- Fermented dough. One who has lived in Alaska for some time, old timer. Alaska produced. (Little used today.)
- Stake**- To mark out confines of a claim. To grubstake. A grubstake, q.v. a part ownership.
- Stampede**- Rush of men to a newly discovered mining district.
- Stamps**- A stamp mill for milling gold.
- Strike**- To find an ore deposit. Newly discovered ore deposit.
- Tailing**- Waste material from which valuable mineral has been extracted.
- Thawed Ground**- Unfrozen ground. This is a prospector's term; inexact because the ground may never have been frozen.
- Trolley**- Cable-suspended car for crossing river.
- Tundra**- Open timberless country covered with moss and niggerheads.
- Undercurrents**- Special riffles which allow large gravel to be carried over or shunted aside.
- Values**- Amount of gold or other valuable mineral recovered or estimated to be in a deposit.
- Wet ground**- Unfrozen ground below water table.
- Wet hole**- Shaft or drill hole that encounters water.
- Wood fire**- To sink a hole in frozen ground by thawing the ground with direct woodfire.
- Yukon sled**- Dog sled without a basket.

BIBLIOGRAPHY

ARRANGEMENT AND SCOPE OF BIBLIOGRAPHY

In Appendix I, the principle types of publications issued by the various agencies were described. Believing that the geological and mining literature dealing with Alaska provides the cheapest base upon which prospecting ventures can be projected, an attempt has been made to include all pertinent publications issued up until 1962 and to arrange these publications by issuing organization and by area of Alaska. Included are publications of the followings: U. S. Geological Survey, the U. S. Bureau of Mines, Bureau of Land Management, University of Alaska, Alaska Division of Mines and Minerals, Alaska Resources Development Board, and a selected General Category.

Information on where to order these publications can be found in Appendix I. Most of the older publications are out of print but can be obtained from second hand bookstores specializing in geological literature.

Most of the publications listed in this bibliography are arranged according to Regions as defined in U. S. Bureau of Mines Information Circular 7679. (See page 359.) Publications dealing with no specific region are listed under "Alaska in General". The arrangement is as follows:

Alaska in General
Alaska Peninsula
Aleutian Islands
Bristol Bay
Cook Inlet-Susitna
Copper River
Kenai Peninsula

Kodiak
Kuskokwim River
Northern Alaska
Seward Peninsula
Southeastern Alaska
Yukon River

The Regions are shown on the map inside the back cover of this book.

PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY

The following publications are listed:

Annual Reports (Ann.Rept.)
Bulletins (Bull.)
Circulars (Circ.)
Maps: GQ Geologic Quadrangle; GP Geophysical; I Miscellaneous Geologic Investigations; MF Mineral Investigations Field Study; OM Oil and Minerals Reserve maps; MR Mineral Investigations; C Coal Investigations
OPEN FILE REPORTS are not listed. These may be examined at U. S. Geological Survey Offices in Alaska.

Professional Papers (Prof. Paper)
Special Publications (Spec. Pub.)
Water Supply Papers (W.S.)

The U. S. Geological Survey publishes periodically a Geological Index Map and Finding List of Commodities and of Areas Listed by Quadrangles and a list of Geologic and Water-Supply Reports on Alaska. These lists are particularly valuable since it is not necessary to go through publications on other areas to find the Alaskan references, and also, open file reports which may contain late information are given. The Survey also publishes as Bulletins a Bibliography of North American Geology. From these bulletins, one can find any article published on North America if the subject or author is known. Other aids to finding specific material in the U. S. Geological Survey literature may be obtained by consulting any of the Alaskan offices of the Survey.

U. S. Geological Survey Maps, Without Regard to Region

TOPOGRAPHIC MAPS - The following topographic maps are used as base maps in U. S. Geological Survey publications:

Base map	A	scale	1:5,000,000	17 in. x 24 in.
B			1:1,500,000	54 in. x 75 in. (Ed. 1950 has scale 1:1,584,000 (54 in. x 78 in.))
C			1:12,000,000	10 in. x 15 in.
E			1:2,500,000	33 in. x 50 in.

The Alaska Topographic Series at a scale of 1:250,000 now gives full coverage of the state. Larger scale maps (1:62,300 and 1:63,360) cover selected areas.

Special Map 54, Central Richardson Highway.

A map of historical interest is Spec. Pub. Map of Alaska showing known gold bearing rocks, with descriptive text containing sketches of the geography, geology and gold deposits and routes to gold fields, 1898.

GEOLOGIC MAPS -

Geologic Map of Alaska, based on Map E, issued in 1957

Coal Fields of United States, Sheet 2, Alaska, 1961

Geologic Map Index of Alaska, 1960 (free)

Geologic maps of selected areas accompany bulletins and professional papers

A number of Geologic Quadrangle Maps of the United States (GQ series) have been issued for Alaska. These maps contain descriptions of geology and supplement the older Bulletins on particular areas.

The following geologic and geophysical maps have been issued exclusive of those which are part of Prof. Papers and Bulletins:

- GQ 100 Juneau B-3
- GQ 110 Fairbanks D-2
- GQ 124 Fairbanks D-1
- GQ 142 Valdez A-5

- GP 135 Aeromagnetic map of Southern Prince of Wales Island, 1956
- GP 156 Aeromagnetic map of Copper River Basin, 1958
- GP 352 Aeromagnetic map of part of the Dillingham Quad., Alaska, 1963
- GP 353 Aeromagnetic map of the Noknek Quad., Alaska, 1963
- GP 354 Aeromagnetic map of parts of the Ugashik and Karluk Quads., Alaska, 1963

- OM 95 Geology of Iniskin Peninsula, Alaska, 1949
- OM 126 Geology of Arctic Slope of Alaska, 1952
- OM 187 Geology of the southeastern part of the Robinson Mountain, Yokotaga district, Alaska, 1957
- OM 189 Reconnaissance geology of the Malaspina district, Alaska, 1957

- I 84 Mesozoic and Cenozoic tectonic elements of Alaska (See Bull.1094.), 1955
- I 197 Geologic Map and Structure Sections Along part of Lower Yukon River, 1956
- I 223 Geologic reconnaissance in the Yukon-Kuskokwim delta regions, Alaska, 1957
- I 226 Geologic Map and Structure Sections of Shaktolik River Area, 1956
- I 230 Salt Chuck area, Prince of Wales Islands (from aerial photos), 1956
- I 231 Hollis area, Prince of Wales Islands, Part 1 (from aerial photos), 1956
- I 232 Hollis area, Prince of Wales Islands, Part 2 (from aerial photos), 1956
- I 243 Reconnaissance geologic map of the Kateel River quad., Alaska, 1958
- I 249 Preliminary geologic map of Nulato and Kateel River areas, Alaska, 1957
- I 269 Ground conditions and surficial geology of the Kenai-Kasilof area, Kenai Peninsula, South Central Alaska, 1958
- Map of Part of Prince William Sound area, Alaska (from aerial photos)
- I 271 Glacial features and surficial deposits of the Malaspina district, Alaska, 1959
- I 273 Map of part of the Prince William Sound area, Alaska (from aerial photos), 1959
- I 276 Progress map of the geology of the Juneau Quadrangle, Alaska, 1958
(Superseded by map I-303)
- I 285 Geology of the Bethel Quadrangle, Alaska, 1960
- I 286 Reconnaissance geologic map of Norton Bay, 1959
- I 287 Reconnaissance geologic map of Candle, 1959
- I 288 Reconnaissance geologic map of Unalakleet, 1959
- I 289 Reconnaissance geologic map of Ruby, 1959
- I 290 Reconnaissance geologic map of Melozitna, 1959
- I 291 Reconnaissance geologic map of Nulato, 1959
- I 292 Russian Mission, 1959
- I 297 Western Part of Big Delta, 1959
- I 303 Juneau Quadrangle, 1959
- I 307 Engineering and Surficial Geology, Nenana-Rex area, 1960
- I 308 Engineering Geology of Katalla area, 1960
- I 312 Nelchina area, 1960
- I 313 Talkeetna Mountains (A-2) and North and Northwest, 1960
- I 314 Talkeetna Mountains (A-1) and part of (B-1), 1960
- I 321 Hagemester Island Quad., 1961
- I 323 Admiralty Island, 1960
- I 339 Goodnews Quad., 1960
- I 340 Fairbanks (D-3) Quad., 1961
- I 341 Traverse across Eastern Chugach Mountains, 1962
- I 342 Anchorage (D-2) Quad., and part of (D-3), 1961
- I 343 Northern two thirds of Anchorage (D-1) Quad., 1961
- I 359 Lower Matanuska Valley, 1962
- I 375 Chandalar, Alaska Quad., 1964
- I 388 Reconnaissance geologic map of Chichagof Island and northwestern Baranof Island, Alaska, 1963
- I 406 Preliminary geologic map of the McCarthy (C-5) Quad., Alaska, 1963

- MF 247 Nome C-1 Quad., 1962
- MF 248 Nome D-1 Quad., 1962

- MR 8 Chromite, Cobalt, Nickel, and Platinum Occurrences in Alaska, 1960
 MR 9 Copper, Lead, and Zinc Occurrences in Alaska, 1960
 MR 10 Molybdenum, Tin, and Tungsten Occurrences in Alaska, 1960
 MR 11 Antimony, Bismuth, and Mercury Occurrences in Alaska, 1960
 MR 32 Lode Gold and Silver Occurrences in Alaska, 1962

Alaska in General

- Prof. Paper 45 The geography and geology of Alaska, a summary of existing knowledge, Brooks, with a section on climate, Abbe, and a topographic map and description thereof, Goode, 1906
 Prof. Paper 159 The Upper Cretaceous floras of Alaska, Hollick, with a description of the plant bearing beds, Martin, 1930
 Prof. Paper 170 a. Glaciation in Alaska, Capps, 1932
 Prof. Paper 182 The Tertiary floras of Alaska, Hollick, with a chapter on the geology of the Tertiary deposits, Smith, 1936
 Prof. Paper 192 Aerial geology of Alaska, Smith, 1939
 Prof. Paper 354 J, K, (J) *Lityuapecten* (New subgenus of *Patinopecten*) from Alaska and California, MacNeil, and (K) Stratigraphic occurrence of *Lityuapecten* in Alaska, Miller, 1961, 1962
 Shorter contributions to general geology
 Prof. Paper 374-C Jurassic (Bathonian or early Callovian) Ammonites from Alaska and Montana, Imlay, 1962
- Bull. 187 Geographic dictionary of Alaska, Baker, 1901
 Bull. 225 Contributions to economic geology, 1903 (Various chapters listed under regions.)
 Bull. 259 Report on progress of investigations of mineral resources of Alaska in 1904, staff, 1905 Contains chapters on placer mining in Alaska, methods and costs of placer mining, southeastern Alaska, Treadwell, Cape Yagtag placers, Turnagain Arm placers, Shumagin Island placers, Unalaska gold lodes, Rampart placers, tin deposits of Alaska, petroleum fields, Bering River coal field, southwestern Alaska coal, Cape Lisbourne coal
 Bull. 263 Methods and costs of gravel and placer mining in Alaska, Purington, 1905
 Bull. 284 Report on progress of investigations of mineral resources of Alaska in 1905 staff, 1906 Contains chapters on administration, the mining industry, railway routes, coal markets, southeastern Alaska lode mining, nonmetallic deposits of southeastern Alaska, Yakutat Bay region, Bering River coal, Prince William Sound copper, Matanuska coal field, Herendeen Bay coal field, Yukon placer fields, Circle to Ft. Hamlin reconnaissance, Seward Peninsula gold mining, York tin region
 Bull. 299 Geographic dictionary of Alaska, Baker, 2nd Ed., McCormick, 1906
 Bull. 314 Report on progress of investigations of mineral resources of Alaska in 1906, staff, 1907
 a. Administrative report, Brooks
 b. Alaska coal fields (See rest of bulletin listed under regions.)
 Bull. 345 Mineral resources of Alaska, report on progress of investigations in 1907, staff
 a. Administrative report, distribution of mineral resources, mining industry in 1907, Brooks; prospecting and mining gold placers in Alaska, Hutchins, recent survey publications
 Bull. 379 Mineral resources of Alaska, report on progress of investigations in 1908, staff
 a. Administrative report; the mining industry 1908; possible use of peat fuel; recent Survey publications
 Bull. 394 Papers on the conservation of mineral resources; mineral resources of Alaska, Brooks, 1909
 Bull. 442 Mineral resources of Alaska, report on progress of investigations in 1909, staff
 a. Mining industry in 1909; Alaska coal and its utilization, Brooks
 b. The preparation and use of peat as fuel, Davis
 j. Alaska coal and its utilization (partial reprint of a.), Brooks
 Bull. 480 Mineral resources of Alaska, report on progress of investigations in 1910, Staff
 a. Administrative report, Brooks; progress of surveys of public lands during 1910, Brooks
 b. The mining industry in 1910, Brooks
 c. Geologic features of Alaskan metalliferous lodes, Brooks
 Bull. 520 Mineral resources of Alaska, report on progress of investigations in 1911, staff
 a. Preface, administrative report; the mining industry in 1911, railway routes from the Pacific seaboard to Fairbanks, Brooks, recent Survey publications
 b. Tin resources of Alaska
 Bull. 542 Mineral resources of Alaska, report on progress of investigations in 1912, staff
 a. Preface, administrative report; the mining industry in 1912, Brooks, recent Survey publications
 Bull. 592 Mineral resources of Alaska, report on progress of investigations in 1913, staff
 a. Preface, administrative report; the mineral deposits of Alaska; the Alaskan mining industry, Brooks; recent Survey publications
 Bull. 622 Mineral resources of Alaska, report on progress of investigations in 1914, staff
 a. Preface administrative report; the Alaskan mining industry in 1914; the future of gold placer mining in Alaska, Brooks; recent Survey publications
 Bull. 642 Mineral resources of Alaska, report on progress of investigations in 1915, staff
 a. Preface, administrative report; the Alaskan mining industry in 1915, Brooks; recent Survey publications
 Bull. 649 Antimony deposits of Alaska, Brooks, 1916
 Bull. 662 Mineral resources of Alaska, report of investigations in 1916, staff, 1918
 a. Administrative report; the Alaskan mining industry in 1916, Brooks; recent Survey publications

- Bull. 666 P. Alaska's mineral supplies, Brooks, 1919
- Bull. 692 Mineral resources of Alaska, report on progress of investigations in 1917, staff
- a. Administrative report; the Alaskan mining industry in 1917, Martin; recent Survey publications
- Bull. 712 Mineral resources of Alaska, report on progress of investigations in 1918,
- a. Alaskan mining industry in 1918, Martin; recent Survey publications
- Bull. 714 Mineral resources of Alaska, report on progress of investigations in 1919, staff
- a. Future of Alaskan mining; the Alaskan mining industry in 1919; Administrative report, Brooks, Martin; recent Survey publications
- Bull. 719 Preliminary report on petroleum in Alaska, Martin, 1921
- Bull. 722 Mineral resources of Alaska, report on progress of investigations in 1920, staff, 1922
- a. The Alaskan mining industry in 1920, Brooks; recent Survey publications
- Bull. 739 Mineral resources of Alaska, report on investigations in 1921, staff
- a. The Alaska mining industry in 1921, Brooks; recent Survey publications
- Bull. 755 Mineral resources of Alaska, report on investigations in 1922, staff
- a. The Alaskan mining industry in 1922, Brooks, Copps; recent Survey publications, 1924
- Bull. 773 Mineral resources of Alaska, report on progress of investigations in 1923, staff
- a. Alaska's mineral resources and production, 1923, Brooks; on early Tertiary placer deposit in the Yenina district, Copps; administrative report, Brooks; recent Survey publications
- Bull. 776 The Mesozoic stratigraphy of Alaska, Martin, 1926
- Bull. 783 Mineral resources of Alaska, report on progress of investigations in 1924, staff
- a. Mineral industry of Alaska in 1924 and administrative report, Smith; selected list of Survey publications
- Bull. 792 Mineral resources of Alaska, report on progress of investigations in 1925, staff
- a. Mineral industry of Alaska in 1925 and administrative report, Moffit; selected list of Survey publications
- Bull. 797 Mineral resources of Alaska, report on progress of investigations in 1926, staff
- a. Mineral industry of Alaska in 1926 and administrative report, Smith; selected list of Survey publications
- Bull. 810 Mineral resources of Alaska, report on progress of investigations in 1927, staff
- a. Mineral industry of Alaska in 1927 and administrative report, Smith; selected list of Survey publications
- Bull. 813 Mineral resources of Alaska, report on progress of investigations in 1928, staff
- a. Mineral industry of Alaska in 1928 and administrative report, Smith; selected list of Survey publications
- Bull. 842 Mineral resources of Alaska, report on progress of investigations in 1929, staff
- a. Mineral industry of Alaska in 1929 and administrative report, Smith; selected list of Survey publications
- Bull. 836 Mineral resources of Alaska, report on progress of investigations in 1930, staff
- a. Mineral industry of Alaska in 1930 and administrative report, Smith; selected list of Survey publications
- Bull. 844 Mineral resources of Alaska, report on progress of investigations in 1931, staff (Only in separate chapters.)
- a. Mineral industry of Alaska in 1931 and administrative report, Smith; selected list of Survey publications
- Bull. 849 Investigations in Alaska Railroad belt, 1931, staff (Issued only in separate chapters. See under regions.)
- Bull. 857 Mineral resources of Alaska, report on progress of investigations in 1932, staff (Issued only in separate chapters.)
- a. Mineral industry of Alaska in 1932, Smith; selected list of Survey publications
- b. Past placer gold production from Alaska, Smith
- Bull. 864 Mineral resources of Alaska, report on progress of investigations in 1933, staff (Issued only in separate chapters.)
- a. Mineral industry of Alaska in 1933, Smith; selected list of Survey publications
- Bull. 868 Mineral resources of Alaska, report on progress of investigations in 1934, staff (Issued only in separate chapters.)
- a. Mineral industry of Alaska in 1934, Smith; selected list of Survey publications
- Bull. 880 Mineral resources of Alaska, report on progress of investigations in 1935, staff (Issued only in separate chapters.)
- a. Mineral industry of Alaska in 1935, Smith
- Bull. 897 Mineral resources of Alaska, report on progress of investigations in 1936, staff (Issued only in separate chapters.)
- a. Mineral industry of Alaska in 1936, Smith
- Bull. 910 Mineral resources of Alaska, report on progress of investigations in 1937, Smith, Mertie (Issued only in separate chapters.)
- a. Mineral industry of Alaska in 1937, Smith
- c. Fineness of gold from Alaska placers, Smith, 1941
- Bull. 917 Mineral resources of Alaska, report on progress of investigations in 1938, Smith, Moffit, Mertie (Issued only in separate chapters.)
- a. Mineral industry of Alaska in 1938, Smith, 1939
- c. Past lode gold production from Alaska, Smith, 1941
- Bull. 926 Mineral resources of Alaska, report on progress of investigations in 1939, Smith, Moffit, Barnes (Issued only in separate chapters.)
- a. Mineral industry of Alaska in 1939, Smith, 1941
- c. Occurrences of molybdenum minerals in Alaska, Smith, 1942

- Bull. 933 Mineral resources of Alaska, report on progress of investigations in 1940, staff (Issued only in separate chapters.)
 a. Mineral industry of Alaska in 1940, Smith, 1941
- Bull. 943 Mineral resources of Alaska, report on progress of investigations in 1943 and 1944 (Issued only in separate chapters.)
 a. Mineral industry of Alaska in 1941 and 1942, Smith, 1944
- Bull. 947 Mineral resources of Alaska, report on progress of investigations in 1943 and 1944 (Issued only in separate chapters.)
 a. Mineral investigations of the Geological Survey in Alaska in 1943 and 1944, Reed
- Bull. 963 Mineral resources of Alaska, 1945-46 (Issued only in separate chapters.)
- Bull. 963-D Photo interpretation of the terrain along the southern part of the Alaska Highway, Raup, Denny, 1950 (Work done in Canada.)
- Bull. 1021 h. Annotated bibliography of Alaskan Paleozoic Paleontology, Dutro, 1956
- Bull. 1061-E Vegetation of northwestern North America, as an aid in interpretation of geologic data, Sigafos, 1958
- Bull. 1067 An introduction to the geology and mineral resources of the continental shelves of the Americas, Trumbull, Lyman, Pepper, Thomasson, 1958
- Bull. 1070-B Lead-alpha ages of the Mesozoic batholiths of western North America, Larsen, Gottfried, Jaffe, Waring, 1958
- Bull. 1082-C Iron-ore resources of the United States including Alaska and Puerto Rico, Carr, Dutton, 1959
- Bull. 1083-A Periodic heat flow in a stratified medium with application to permafrost problems, Lachenbruch, 1959
- Bull. 1094 Possible Petroleum provinces in Alaska, Miller, Payne Gryc, Cobb, 1959
- Bull. 1136 Coal reserves of the United States --A progress report, Jan. 1, 1960, Averitt, 1961
- Bull. 1139. Index of metallic and nonmetallic mineral deposits of Alaska compiled from published reports of Federal and State agencies through 1959, Cobb, Kachadoorian, 1961
- W. S. 418 Mineral Springs of Alaska, Waring, with a chapter on the chemical character of some surface waters of Alaska, Dole, Chambers, 1917
- W. S. 955 Index to river surveys made by the U. S. Geological Survey and other agencies, Jones, Hellend, 1948
- W. S. 992 Bibliography and index of publications relating to ground water prepared by the U. S. Geological Survey and cooperating agencies, Waring, Meinzer, 1947
- W. S. 1486 Quantity and quality of surface waters of Alaska, 1953-1956, 1959
- W. S. 1500 Quantity and quality of surface waters of Alaska, 1957, 1960
- W. S. 1720 Quantity and quality of surface waters of Alaska, 1960, 1962
- Circ. 101 Surveying and mapping in Alaska, Fitzgerald, 1951
- Circ. 157 Annotated bibliography and index map of sulphur and pyrites deposits in the United States and Alaska, Espenshade, Broedel, 1952
- Circ. 169 Summary of ground water development in Alaska, Cederstrom, 1950
- Circ. 184 Reconnaissance for radioactive deposits in south central Alaska, 1947-49, Moxham, Nelson, 1952
- Circ. 196 Preliminary summary of reconnaissance for uranium in Alaska, 1951, White, West, Talbert, Nelson, Houston, 1952
- Circ. 202 Preliminary summary review of the thorium-bearing mineral occurrences in Alaska, Bates, Wedow, 1952
- Circ. 248 Preliminary summary of reconnaissance for Uranium and thorium in Alaska, 1952, Wedow, others, 1953
- Circ. 275 Occurrence and development of ground water in permafrost regions, Cederstrom, Johnson, Subitzky, 1953
- Circ. 281 Bibliography of U. S. Geological Survey Trace Elements and related reports, Curtis, Houser, 1953
- Circ. 289 Multiple glaciation in Alaska, Plavé, others, 1953
- Circ. 293 Coal resources of the United States, Averitt, Berryhill, Taylor, 1953
- Ann. Rept. 17, Part I e Report on coal and lignite of Alaska, Dall, 1896
- Ann. Rept. 21, Part II j Alaskan geographic names, Baker, 1900
- Spec. Pub. Maps and descriptions of routes of exploration in Alaska in 1898, with general information concerning the Territory, 1899
- Spec. Pub. Press releases, preliminary maps and preliminary reports released by the Geologic Branch and Alaskan Branch
 List 1-Jan. 1, 1938 to Jan. 1, 1945, 1945 (processed)
 List 2-Jan. 1, 1945 to Jan. 1, 1946, 1947 (processed)

Alaska Peninsula

- Prof. Paper 132 j. Aniakchak crater, Alaska peninsula, Smith, 1925
 Prof. Paper 249 b. Callovian (Jurassic) ammonites from the United States and Alaska, Part 2 Alaska Peninsula and Cook Inlet regions, Imlay, 1953
- Bull. 284. See under Alaska in General (The Herendeen Bay coal field), Paige, 1906
 Bull. 379 c. Mineral resources of southwestern Alaska, Atwood, 1909
 Bull. 467. Geology and mineral resources of parts of the Alaska Peninsula, Atwood, 1911
 Bull. 739 c. Recent investigations of petroleum in Alaska (Cold Bay, Iniskin Bay, Anchorage, Nenana coal field), Capps, Moffit, Brooks, Martin, 1923
 Bull. 755 d. The Cold Bay-Chignik district, Alaska, Smith, Baker, 1924
 Bull. 773 d. The Cold Bay-Katmai district, Smith. The outlook for petroleum near Chignik, Martin, 1925
 Bull. 783 c. Geology and oil developments of the Cold Bay district, Smith, 1926
 Bull. 797 f. Geology and mineral resources of the Aniakchak district, Knappen, 1929
 Bull. 857 d. Notes on the geology of the Alaska peninsula and the Aleutian Islands, Capps, 1934
 Bull. 1028. Investigations of Alaskan Volcanoes, 1955 (Issued in separate chapters.) i. j. k. l. m. n. are regional studies, Snider, et. al. Part n. is: Some effects of recent volcanic ash falls, with special reference to Alaska, Wilcox, 1959
 Bull. 1058 g. Geology of Mt. Katmai area, Alaska, Keller, Reiser, 1959
- Circ. 318. Eruption of Mt. Tridant Volcano, Katmai National Monument, Alaska, White, West, 1954
- Ann. Rept. 18, Part III a. Reconnaissance of the gold fields of southern Alaska, with some notes on general geology, Becker, 1897
 Ann. Rept. 20, Part VII a. Reconnaissance in the Sushitna basin and adjacent territory, Alaska in 1898, Eldridge, 1899
 Part VII b. Reconnaissance in southwestern Alaska in 1898, Spurr, 1899

Aleutian Islands

- Prof. Paper 454-B, C, Intrusive layered lava pods and pillowed lavas, Unalaska Island, Alaska, and Pillowed lavas II: A review of selected recent literature, Snyder, Fraser, 1963
- Bull. 259 (See under Alaska in General.) Gold deposits of the Shumagin Islands, Martin; Auriferous quartz veins on Unalaska Island, Collier, 1905
- Bull. 692 e. Sulphur on Unalaska and Akun Islands and near Stepovak Bay, Maddren, 1919
- Bull. 857 d. Notes on the geology of the Alaska peninsula and the Aleutian Islands, Capps, 1934
- Bull. 974 b. Volcanic activity in the Aleutian Arc, Coats, 1950
- Bull. 989 a. Geology of Buldir Island, Aleutian Islands, Alaska, Coats, 1953
- Bull. 1028 a., b., c., d., e., f., Geology of Aleutian and Pribilof Islands, Alaska, Coats, Kennedy, Waldron, Simmons, Mathewson, Barth, 1955 (Issued as separate Bulletins.)
- Ann. Rept. 18 Part III a. Reconnaissance of the gold fields of southern Alaska, with some notes on general geology, Becker, 1897

Bristol Bay

- Bull. 379 c. Mineral resources of southwestern Alaska, Atwood, 1909
- Bull. 442 e. Outline of the geology and mineral resources of the Iliamna and Clark Lakes region, Martin, Katz; Gold placers of the Mulchatna, Katz, 1910
- Bull. 622 h. Mineral resources of the Lake Clark-Iditarod region, Smith, 1915
- Bull. 655 The Lake Clark-Central Kuskokwim region, Alaska, Smith, 1917
- Bull. 824 c. The Lake Clark-Mulchatna region, Capps, 1932
- Bull. 862 The southern Alaska Range, Capps, 1934
- Bull. 903 The Nushagak district, Alaska, Mertie, 1938
- Bull. 1028 Investigations of Alaskan Volcanoes, i., j., k., l., m., n., Snider, et. al. 1955 (Issued in separate chapters.) Part n. is: Some effects of recent volcanic ash falls, with special reference to Alaska, Wilcox, 1959
- Circ. 207 Reconnaissance for radioactive deposits in the southern Cook Inlet region, Alaska, Moxham, 1949, Nelson, 1952
- Circ. 318 Eruption of Trident Volcano, Katmai National Monument, Alaska, February-June, 1953, Snyder, 1954
- Ann. Rept. 18, Part III a. Reconnaissance of the gold fields of southern Alaska, with some notes on general geology, Becker, 1897
- Ann. Rept. 20, Part VII b. Reconnaissance in southwestern Alaska in 1897, Spurr

Cook Inlet-Susitna

- Prof. Paper 70 The Mt. McKinley region, Alaska, Brooks, with descriptions of the igneous rocks and the Bonfield and Kantishna districts, Prindle, 1911
- Prof. Paper 249 b. Cretaceous (Jurassic) ammonites from the United States and Alaska Part 2. Alaska Peninsula and Cook Inlet regions, Imlay, 1953
- Prof. Paper 316 G. An aeromagnetic reconnaissance of the Cook Inlet area, Alaska, Granz, Zietz, Andreasen, 1963
- Prof. Paper 354 D. Early Cretaceous (Albian) ammonites from the Chitina Valley and Talkeetna Mountains, Alaska, Imlay, 1963
- Prof. Paper 418 A. Late Bajocian ammonites from the Cook Inlet region, Alaska, Imlay, 1962
- Bull. 259 (See under Alaska in General.)
- Bull. 277 Gold fields of the Turnagain Arm region, Moffit, 1906; coal fields of the Kachemak Bay region, Stone, 1906
- Bull. 284 (See under Alaska in General.)
- Bull. 379 c. Mineral resources of southwestern Alaska, Atwood, 1909
- Bull. 314 f. Reconnaissance in the Matanuska and Talkeetna Basins, Alaska, with notes on the placers of the adjacent regions, Paige, Moffit, 1907
- Bull. 327 Geologic reconnaissance in the Matanuska and Talkeetna Basins, Alaska, Paige, Knopf, 1907
- Bull. 480 e. The upper Susitna and Chistochina districts, Moffit, 1911
- f. Preliminary report on a detailed survey of part of the Matanuska coal fields, Martin; a reconnaissance of the Willow Creek gold region, Katz
- Bull. 498 Headwater regions of Gulkana and Susitna Rivers, Alaska, with accounts of the Valdez Creek and Chistochina placer districts, Moffit, 1912
- Bull. 500 Geology and coal fields of the lower Matanuska Valley, Alaska, Martin, Katz, 1912
- Bull. 520 f. Gold placers of the Yentna district, Capps, 1912
- Bull. 534 The Yentna district, Alaska, Capps, 1913
- Bull. 592 h. Gold lodes and placers of the Willow Creek district, Capps; mineral resources of the upper Matanuska and Nelchina valleys, Martin, Mertie; preliminary report on the Broad Pass region, Moffit, 1914
- Bull. 607 The Willow Creek district, Alaska, Capps, 1915
- Bull. 608 The Broad Pass region, Alaska, Moffit, with sections on quaternary deposits, igneous rocks, and glaciation, Pogue, 1915
- Bull. 622 d. Auriferous gravels of the Nelchina-Susitna region, Chapin, 1915
- Bull. 642 e. The Turnagain-Knik region, Capps, 1916
- f. Gold mining in the Willow Creek district, Capps, 1916
- Bull. 668 The Nelchina-Susitna region, Alaska, Chapin, 1918
- Bull. 692 c. Mining in central and northern Kenai Peninsula, Johnson, 1919
- d. Gold lode mining in the Willow Creek district; mineral resources of the western Talkeetna Mountains; mineral resources of the upper Chulitna region, Capps, 1919; Platinum bearing gold placers of the Kahiltna Valley; Chromite deposits of Alaska, Mertie; geologic problems at the Matanuska coal mines, Martin, 1919
- Bull. 712 d. Preliminary report on the chromite of Kenai Peninsula, Gill, 1920
- e. Mining developments in the Matanuska coal fields; lode developments in the Willow Creek district, Chapin
- Bull. 714 d. Mining developments in the Matanuska coal fields; lode developments in the Willow Creek district, Chapin, 1921
- Bull. 719 Preliminary report on petroleum in Alaska, Martin, 1921
- Bull. 722 d. Geology of the vicinity of Tuxedni Bay, Cook Inlet, Moffit, 1922
- Bull. 739 c. Recent investigations of petroleum in Alaska (Cold Bay, Iniskin Bay, Anchorage, Nenana Coal field), Capps, Moffit, Brooks, Martin, 1923
- Bull. 755 c. Geology and mineral resources of the region traversed by the Alaska Railroad, Capps, 1924
- Bull. 773 d. Petroleum on Alaska Peninsula; mineral resources of the Kamishak Bay region, Mather, 1925
- Bull. 783 c. A ruby silver prospect in Alaska, Capps, Short, 1926
- Bull. 789 The Iniskin-Chinitna Peninsula and the Snug Harbor district, Alaska, Moffit, 1927
- Bull. 791 Geology of the upper Matanuska Valley, Alaska, Capps, with a section on igneous rocks, Mertie, 1927
- Bull. 792 b. Geology of the Knik-Matanuska district, Alaska, Landes, 1927
- Bull. 797 b. The Skwentna region, Capps, 1929
- Bull. 810 c. The Mount Spurr region, Capps, 1930
- Bull. 813 b. The Chakachoma-Stony region, Capps, 1930
- Bull. 844 b. Mineral investigations in the Alaska Railroad belt, 1931, Capps, 1933
- Bull. 849 a. Progress of surveys in the Anthracite Ridge district, Alaska, Richards, Waring, 1933
- c. The Willow Creek gold-lode district, Alaska, Ray, 1933
- d. The Mt. Eielson district, Alaska, Reed, 1933
- e. Mineral deposits near the west fork of the Chulitna River, Alaska, Ross, 1933
- f. The Girdwood district, Alaska, Park, 1933
- g. The Valdez Creek mining district, Alaska, Ross, 1933
- h. The Moose Pass-Hope district, Kenai Peninsula, Alaska, Tuck, 1931
- i. The Moose Pass-Hope district, Kenai Peninsula, Alaska, Tuck, 1931
- Bull. 857 e. Core drilling for coal in the Moose Creek area, Alaska, Waring, 1934
- Bull. 861 Geology of the Anthracite Ridge region, Alaska, Waring, 1936

- Bull. 862 The southern Alaska Range, Capps, 1935
 Bull. 864 b. The Willow Creek-Kashwitna district, Alaska, Capps, Tuck, 1935
 Bull. 880 d. The Eska Creek coal deposits, Matanuska Valley, Tuck, 1937
 Bull. 897 b. The Valdez Creek mining district in 1936, Tuck, 1938
 Bull. 907 Geology of the Alaska Railroad region, Capps, 1940
 Bull. 926 d. Geology of the Portage Pass area, Alaska, Barnes, 1943
 Bull. 931 g. Chromite deposits of Kenai Peninsula, Alaska, Guild, 1942
 Bull. 933 c. Relations of structure to mineral deposition at the Independence mine, Alaska, Stoll, 1944
 Bull. 963 e. Coal investigations in South Central Alaska, 1944-1946, Barnes, others, with a section on clay deposits on Healy Creek, Cobb, 1951
 Bull. 989 c. Gypsiferous deposits on Sheep Mountain, Alaska, Eckhart, 1953
 Bull. 1004 Geology and ore deposits of the Willow Creek mining district, Alaska, Ray, 1954
 Bull. 1016 The Wishbone Hill district, Matanuska Coal Field, Alaska, Barnes, Payne, 1956
 Bull. 1024 a. Radioactivity investigations in the Cache Creek area, Yentna district, Alaska, Robinson, Wedow, Lyons, 1955
 Bull. 1024 d. Magnetite deposits at Tuxedni Bay, Alaska, Grantz, 1956
 Bull. 1039 a. Marl deposits in the Knik Arm area, Alaska, Moxham, Eckhart, 1956
 Bull. 1039 c. Haydite Raw Material in the Kings River, Sutton and Lawing areas, Alaska, Eckhart, Plafker, 1959
 Bull. 1058 d. The Little Susitna district, Matanuska Coalfield, Alaska, Barnes, Sokol, 1959
 Bull. 1093 Surficial geology of Anchorage and vicinity, Alaska, Miller, Dobrovalny, 1959
 Bull. 1108 a. Geology of the Mount McKinley quadrangle, Alaska, Reed, 1961
 Bull. 1121 c. Eolian deposits of the Matanuska Valley agricultural area, Alaska, Trainer, 1961
- W.S. 372 A water-power reconnaissance in south-central Alaska, Ellsworth, Davenport, with a section on southeastern Alaska, Hoyt, 1915
- Circ. 18 Nonmetalliferous deposits in the Alaska Railroad belt, Waring, 1947
 Circ. 154 Coal prospects and recent coal exploration and development in the lower Matanuska Valley, Alaska in 1950, Barnes, Ford, 1952
 Circ. 184 Reconnaissance for radioactive deposits in south-central Alaska, 1947-49, Moxham, Nelson, 1952
 Circ. 207 Reconnaissance for radioactive deposits in the southern Cook Inlet region, Alaska, 1949, Moxham, Nelson, 1952
 Circ. 268 Preliminary report on the geology and ground water resources of the Matanuska Valley agricultural area, Alaska, Trainer, 1953
- Ann. Rept. 20, 1899, VII a. A reconnaissance in the Sushitna basin and adjacent territory, Alaska in 1898, Eldridge
 b. A reconnaissance in southwestern Alaska in 1898, Spurr
 c. A reconnaissance from Resurrection Bay to the Tonana River, Alaska in 1898, Spurr
 d. A reconnaissance of a part of Prince William Sound and the Copper River district, Alaska in 1898, Schrader

Copper River

- Prof. Paper 15 The mineral resources of the Maunt Wrangell district, Alaska, Mendenhall, Schrader, 1903
 Prof. Paper 41 Geology of the Central Copper River region, Alaska, Mendenhall, 1905
 Prof. Paper 98 c. Retreat of Barry Glacier, Port Wells, Prince William Sound, Alaska, between 1910 and 1914, Johnson, 1917
 Prof. Paper 354 c. Giant waves in Lituya Bay, Alaska, Miller, 1960
 Prof. Paper 354 d. Early Cretaceous (Albian) ammonites from the Chitina Valley and Talkeetna Mountains, Alaska, Imlay, 1960
- Bull. 213 Contributions to economic geology, 1903; Chistochina gold fields, Mendenhall, 1903
 Bull. 225 Contributions to economic geology, 1903, petroleum fields of Alaska and the Bering River coal fields, Martin
 Bull. 259 (See under Alaska in General.)
 Bull. 284 (See under Alaska in General.)
 Bull. 314 d. Reconnaissance from Yakutat to Alsek River, Blackwelder, 1907
 Bull. 314 e. Petroleum of Controller Bay, Martin, 1907
 Bull. 335 Geology and mineral resources of the Controller Bay region, Alaska, Martin, 1908
 Bull. 345 c. The mineral resources of the Kotsina and Chitina valleys, Copper River region, Moffit, Maddren; notes on copper prospects of Prince William Sound, Moffit, 1908
 Bull. 374 Mineral resources of the Kotsina-Chitina region, Alaska, Prindle, 1909
 Bull. 379 c. Copper mining and prospecting on Prince William Sound; geology and mineral prospects in the vicinity of Seward, Kenai Peninsula; mineral resources of Southwestern Alaska, Grant, Higgins, Atwood, 1909
 Bull. 379 d. Mining in the Kotsina-Chitina, Chistochina, and Valdez Creek regions, Moffit, 1909
 Bull. 442 d. Mining in the Chitina district, Moffit, 1910; mining and prospecting on Prince William Sound in 1909, Grant
 Bull. 443 Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska, Grant, Higgins, 1913
 Bull. 448 Geology and mineral resources of the Nizina district, Alaska, Moffit, Capps, 1911
 Bull. 480 e. The upper Sushitna and Chistochina districts, Moffit, 1911
 Bull. 498 Headwater regions of the Gulkana and Sushitna Rivers, Alaska, with accounts of the Valdez Creek and Chistochina placer districts, Moffit, 1912
 Bull. 520 c. The Tarol and Bremner River districts, Moffit; the Chitina copper district, Moffit, 1912
 Bull. 520 d. Gold deposits near Valdez, Brooks, 1912
 Bull. 526 Coastal glaciers of Prince William Sound and Kenai Peninsula, Alaska, Grant, Higgins, 1913
 Bull. 542 c. The McKinley Lake district, Chapin; mining in Chitina Valley, Moffit, 1913
 Bull. 576 Geology of the Hanagita-Bremner region, Alaska, Moffit, 1914
 Bull. 592 e. Mineral deposits of the Yakutat district, Maddren, 1914
 f. Preliminary report on a water power reconnaissance in south central Alaska, Ellsworth, Davenport, 1914
 g. The Port Wells gold lode district; mining on Prince William Sound, Johnson, 1914
 h. (a portion) Mining in the Valdez Creek placer district, Moffit, 1914
 Bull. 605 The Ellamar district, Alaska, Copps, Johnson, 1915
 Bull. 622 d. Mineral deposits of the Kotsina-Kuskulana district, with notes on mining in Chitina Valley, Moffit; auriferous gravels of the Nelchina-Sushitna region, Chapin, 1915
 e. Mining on Prince William Sound; the gold and copper deposits of the Port Valdez district, Johnson, 1915
 Bull. 642 c. Mineral resources of the upper Chitina Valley, Moffit, 1916
 d. Mining on Prince William Sound, Johnson, 1916
 Bull. 662 c. Mining in the lower Copper River basin, Moffit; mining on Prince William Sound, Johnson; copper deposits of the Lotouche and Knight Island districts, Prince William Sound, Johnson, 1918
 Bull. 668 The Nelchina-Sushitna region, Alaska, Chapin, 1918
 Bull. 675 The upper Chitina Valley, Alaska, Moffit, with a description of the igneous rocks, Overbeck, 1918
 Bull. 692 c. Platinum-bearing auriferous gravels of the Chistochina river, Chapin; mining on Prince William Sound, Johnson; mineral resources of Jack Bay district and vicinity, Prince William Sound, Johnson, 1919
 Bull. 712 c. Nickel deposits in the lower Copper River valley, Overbeck, 1920
 Bull. 714 c. Mining in the Chitina Valley, Moffit, 1921
 Bull. 745 The Kotsina-Kuskulana district, Alaska, Moffit, Mertie, 1923
 Bull. 755 b. The metalliferous deposits of the Chitina Valley, Alaska, Moffit, 1924
 Bull. 773 c. The occurrence of Copper on Prince William Sound, Alaska, Moffit, 1925
 Bull. 813 d. Notes on the geology of upper Nizina River, Moffit, 1930
 Bull. 824 b. The Slana district, upper Copper River region, Moffit, 1932
 Bull. 836 b. Notes on geography and geology of Lituya Bay, Mertie, 1933
 Bull. 844 c. The Suslota Pass district, upper Copper River region, Alaska, Moffit, 1934
 Bull. 866 Geology of the Tonsina district, Alaska, Moffit, 1935
 Bull. 868 c. Upper Copper and Tanana Rivers, Moffit, 1936
 Bull. 880 b. Recent mineral developments in the Copper River region, Moffit, 1937
 Bull. 894 Geology of the Chitina Valley and adjacent area, Alaska, Moffit, 1938
 Bull. 904 Geology of the Slana-Tok district, Alaska, Moffit, 1938

- Bull. 926 d. Geology of the Portage Pass area, Barnes, 1943
 Bull. 943 b. Mining in the northern Copper River region, Alaska, Moffit, 1944
 c. Nickel-copper prospect near Spirit Mountain, Copper River region, Alaska, Kingston, Miller
 Bull. 947 e. Copper bullion claims, Rua Cove, Knight Island, Alaska, Stefansson, Moxham, 1946
 Bull. 947 f. Copper deposits of the Nizina district, Alaska, Miller, with an introduction by Moffit, 1946
 g. Copper deposits of the Kotzina-Kuskulana district, Alaska, Van Alstine, Black, with an introduction by Moffit, 1946
 Bull. 963 b. Copper deposits of the Prince William Sound district, Alaska, Moffit, Fellows, 1950
 Bull. 989 d. Geology of the eastern part of the Alaska Range and adjacent area, Alaska, Moffit, 1954
 Bull. 1024 e. Pyrite deposits at Horseshoe Bay, Latouche Island, Alaska, Stejer, 1956
 W. S. 372 A Water power reconnaissance in south-central Alaska, Ellsworth, Davenport, with a section on southeastern Alaska, Hoyt, 1915
 W. S. 1779 a. Geologic reconnaissance and test-well drilling, Cordova, Alaska, Walters, 1963
 Circ. 136 Geology at the site of a proposed dam and reservoir on Power Creek near Cordova, Alaska, 1951
 Circ. 146 A review of the geology and coal resources of the Bering River coal field, Alaska, Barnes, 1951
 Circ. 184 Reconnaissance for radioactive deposits in south-central Alaska, 1947-49, Moxham, Nelson, 1952
 Ann. Rept. 13, Part II a. Second expedition to Mt. St. Elias in 1891, Russell, 1892
 Ann. Rept. 18, Part III a. Reconnaissance of the gold fields of southern Alaska, with some notes on general geology, Becker, 1897
 Ann. Rept. 20, Part VII c. A reconnaissance from Resurrection Bay to the Tanana River, Alaska in 1898, Mendenhall, 1898
 d. A reconnaissance of a part of Prince William Sound and the Copper River district, Alaska in 1898, Schrader
 Ann. Rept. 21, Part II h. A reconnaissance of the Chitina River and the Skolai Mountains, Alaska, Rohn
 Spec. Pub. The geology and mineral resources of a portion of the Copper River district, Alaska, Schrader, Spencer, 1901

Kenai Peninsula

- Bull. 277 Mineral resources of Kenai Peninsula, Alaska, Moffit, 1906
 Bull. 379 c. Mineral prospects in the vicinity of Seward, Kenai Peninsula, Grant, Higgins, 1907
 Bull. 442 d. Preliminary report on the mineral resources of the southern part of Kenai Peninsula, Grant, Higgins, 1910
 Bull. 520 e. Gold deposits of the Seward-Sunrise region, Kenai Peninsula, Johnson, 1912

- Bull. 526 Coastal glaciers of Prince William Sound and Kenai Peninsula, Alaska, Grant, Higgins, 1913
 Bull. 587 Geology and mineral resources of Kenai Peninsula, Alaska, Martin, Johnson, Grant, 1915
 Bull. 931 g. Chromite deposits of Kenai Peninsula, Alaska, Guild, 1942
 Bull. 1031 a. Geologic investigations of proposed power sites at Cooper, Grant, Ptarmigan, and Crescent Lakes, Alaska, Pfafker, 1955
 Bull. 1039 b. Occurrence of diatomaceous earth near Kenai, Alaska, Pfafker, 1956
- Circ. 207 Reconnaissance for radioactive deposits in the Southern Cook Inlet region, Alaska, 1949, Moxham, Nelson, 1952
- Ann. Rept. 18, Part III a. Reconnaissance of the gold fields of southern Alaska, with some notes on general geology, Becker, 1897
 Ann. Rept. 20, Part VII a. A reconnaissance in the Sushitna basin and adjacent territory, Eldridge, 1899
 b. A reconnaissance in southwestern Alaska in 1898, Spurr
 c. A reconnaissance from Resurrection Bay to the Tanana River, Alaska in 1898, Mendenhall

Kodiak Island

- Bull. 542 e. Mineral deposits of Kodiak and the neighboring islands, Martin, 1913
 Bull. 692 e. The beach placers of Kodiak Island, Maddren, 1919
 Bull. 868 b. Kodiak and vicinity, Capps, 1937
 Bull. 880 c. Kodiak and adjacent islands, Capps, 1937
- Ann. Rept. 18, Part III a. Reconnaissance of the gold fields of southern Alaska, with some notes on general geology, Becker, 1897
 Ann. Rept. 20, Part VII a. A reconnaissance in the Sushitna basin and adjacent territory, Alaska in 1898, Eldridge, 1899

Kuskokwim

- Prof. Paper 268 The Central Kuskokwim region, Alaska, Cady, Wallace, Hoare, Webber, 1955
- Bull. 410 The Innoko gold placer district, Alaska, with accounts of the central Kuskokwim Valley and the Ruby Creek and Gold Hill placers, Maddren, 1910
- Bull. 622 h. Mineral resources of the Lake Clark-Iditarod region, Smith, 1915; Quicksilver deposits of the Kuskokwim region, Smith, Maddren; Gold placers of the lower kuskokwim with a note on copper in the Russian Mountains, Maddren, 1915
- Bull. 642 h. Exploration in the Cosna-Nowitna region, Eakin; mineral resources of the Ruby-Kuskokwim region, Mertie, Harrington, 1916
- Bull. 655 The Lake Clark-Central Kuskokwim region, Alaska, Smith, 1917
- Bull. 714 e. Mineral resources of the Goodnews Bay region, Harrington, 1921
- Bull. 722 e. Gold lodes of the upper Kuskokwim region, Martin, 1922
- Bull. 739 d. The occurrence of metalliferous deposits in the Yukon and Kuskokwim regions, Mertie, 1923
- Bull. 754 The Ruby-Kuskokwim region, Alaska, Mertie, Harrington, 1924
- Bull. 783 d. The Nixon Fork country and silver-lead prospects near Ruby, Brown, 1926
- Bull. 792 c. The Toklat-Tonzona River region, Capps, 1927
- Bull. 813 b. The Chakachamna-Stony region, Capps, 1930
- Bull. 846 c. Mineral deposits of the Ruby-Kuskokwim region, Mertie, 1936
- Bull. 910 b. Platinum deposits of the Goodnews Bay district, Alaska, Mertie, 1939
- Bull. 918 The Goodnews Bay platinum deposits, Alaska, Mertie, 1940
- Bull. 1071 g. Geomorphology of the upper Kuskokwim region, Alaska, Fernald, 1960
- Bull. 1142 g. Geology of the Red Devil quicksilver mine, Alaska, MacKevett, Berg, 1963
- Circ. 255 Reconnaissance for radioactive deposits in the lower Yukon-Kuskokwim region, Alaska, 1947, White, Killen, 1953
- Circ. 279 Reconnaissance for radioactive deposits in the Ruby-Poorman and Nixon Forks districts, west-central Alaska, White, Stevens, 1953
- Circ. 328 Reconnaissance for radioactive deposits in the lower Yukon-Kuskokwim region, Alaska, 1952, West, 1954
- Ann. Rept. 20, Part VII b. A reconnaissance in southwestern Alaska in 1898, Spurr, 1899

Northern Alaska

- of. Paper 20 A reconnaissance in Northern Alaska cross the Rocky Mountains along Koyukuk, John, Anaktuvuk and Colville Rivers and the Arctic Coast to Cape Lisbourne in 1901, Schrader, with notes by Peters, 1904
- of. Paper 85 d. The Jurassic flora of Cape Lisbourne, Alaska, Knowlton, 1914
- of. Paper 109 The Canning River region, northern Alaska, Leffingwell, 1919

- Prof. Paper 125 c. Pliocene and pleistocene fossils from the Arctic Coast of Alaska and the auriferous beaches of Nome, Norton Sound, Alaska, Dall, 1921
- Prof. Paper 236 b. Foraminifera from the Arctic Slope of Alaska, Triassic and Jurassic, Tappan, 1951
- Prof. Paper 274 d. Characteristic Jurassic mollusks from northern Alaska, Inlay, 1955
- Prof. Paper 283 Mississippian Cephalopods of northern and eastern Alaska, Gordon, 1957
- Prof. Paper 301 Exploration of Naval Petroleum Reserve No. 4 and adjacent areas, northern Alaska, 1944-53, Part I, History of the exploration, Reed, 1958
- Prof. Paper 302 a. Phosphate deposits in northern Alaska, Patton, Matzko, 1959
- b. Vegetation of the Arctic slope of Alaska, Spetzman, 1959
- Prof. Paper 303 Exploration of Naval Petroleum Reserve No. 4 and adjacent areas, northern Alaska, 1944-53, a. The Paleozoic section in the Sainin Lake area, central Brooks Range, Alaska, Bowsher, Dutro, 1957
- b. A new upper Paleozoic formation, central Brooks Range, Alaska, Patton, 1957
- e. Geology of the Chandler River region, Alaska, Detterman, Bickel, Gryc, 1963
- part 3 Areal geology
- Prof. Paper 304 a. Seismic and gravity surveys of Naval Petroleum Reserve No. 4 and adjacent areas, Alaska, Woolson, others, 1962 (1963)
- Prof. Paper 305, part 5 Subsurface geology and engineering data
- Prof. Paper 334 e. Upper Cretaceous Pelecypods of the genus *Inoceramus* from northern Alaska, Jones, Gryc, 1960
- Prof. Paper 335 Characteristic lower Cretaceous megafossils from northern Alaska, Inlay, 1961
- Bull. 259 (See under Alaska in General.)
- Bull. 278 Geology and coal resources of the Cape Lisbourne region, Alaska, Collier, 1906
- Bull. 719 Preliminary report on petroleum in Alaska, Martin, 1921
- Bull. 722 A reconnaissance of the Point Barrow region, Alaska, Paige, Foran, Gilluly, 1925
- Bull. 783 e. Summary of recent surveys in northern Alaska, Smith, Mertie, Foran, 1926
- Bull. 792 c. Geologic investigations in northern Alaska, Smith, 1927
- Bull. 797 d. Surveys in northwestern Alaska in 1926, Smith, 1929
- Bull. 815 Geology and mineral resources of northwestern Alaska, Smith, Mertie, 1930
- Bull. 1083 c. Dissipation of the temperature effect of drilling a well in Arctic Alaska, Lachenbruch, Brewer, 1959

Northwestern Alaska

Prof. Paper 10 Reconnaissance from Ft. Hamlin to Kotzebue Sound, Alaska by way of Dall, Kanuti, Allen and Kowak Rivers, Mendenhall, 1902

- Bull. 480 j. The Shungnak region, Kobuk Valley, Smith, Eakin; the Squirrel River placers, Smith, 1911
- Bull. 520 l. The Alatna-Noatak region, Smith, 1912
- Bull. 536 The Noatak-Kobuk region, Alaska, Smith, 1913
- Bull. 712 g. Mining in northwestern Alaska, Cathcart, 1920
- Bull. 797 d. Surveys in northwestern Alaska in 1926, Smith, 1929
- Bull. 815 Geology and mineral resources of northwestern Alaska, Smith, Mertie, 1930

Seward Peninsula

Prof. Paper 2 A reconnaissance of the northwestern portion of Seward Peninsula, Alaska, Collier, 1902
 Prof. Paper 125 c. Pliocene and Pleistocene fossils from the Arctic Coast of Alaska and the auriferous beaches of Nome, Norton Sound, Alaska, Dall, 1921

- Bull. 225 Contributions to economic geology, 1903; Kotzebue placer gold field of Seward Peninsula, Alaska, Moffit, 1904
- Bull. 229 The tin deposits of the York region, Alaska, Collier, 1904
- Bull. 247 The Fairhaven gold placers, Seward Peninsula, Alaska, Moffit, 1905
- Bull. 259 (See under Alaska in General.)
- Bull. 284 (See under Alaska in General.)
- Bull. 314 g. The Nome region, Alaska, Moffit, 1907
 - h. Gold fields of the Solomon and Niukluk River basins, Smith; geology and mineral resources of Iron creek, Smith, 1907
 - i. Kougak region, Alaska, Brooks, 1907
 - j. Water supply of the Nome region, Seward Peninsula, 1906, Hoyt, Henshaw, 1907
- Bull. 328 The gold placers of parts of Seward Peninsula, Alaska, including the Nome, Council, Kougak, Port Clarence and Goodhope precincts, Collier, Hess, Smith, Brooks, 1908
- Bull. 345 e. Investigations of the mineral deposits of Seward Peninsula, Smith; the mineral deposits of the Lost River and Brooks Mountain region, Seward Peninsula, Knopf; water supply of the Nome and Kougak regions, Seward Peninsula, 1906-07, Henshaw
- Bull. 358 Geology of the Seward Peninsula tin deposits, Alaska, Knopf, 1908
- Bull. 379 f. Recent developments in southern Seward Peninsula; the Iron Creek region; mining in the Fairhaven precinct; water supply investigations in Seward Peninsula, Smith, Henshaw, 1908
- Bull. 442 h. Mineral resources of the Nulato-Council region, Smith, Eakin, 1910
 - i. Mining on Seward Peninsula, Henshaw; water supply investigations in Seward Peninsula, 1909, Henshaw, 1910
- Bull. 449 A geologic reconnaissance in southeastern Seward Peninsula and the Norton Bay-Nulato region, Alaska, Smith, Eakin, 1911
- Bull. 520 b. Tin resources of Alaska, Hess, 1912
 - m. Notes on mining in Seward Peninsula, Smith, 1912
- Bull. 533 Geology of the Nome and Grand Central quadrangles, Alaska, Moffit, 1913
- Bull. 592 l. Placer mining on Seward Peninsula; Lode developments on Seward Peninsula, Chapin, 1914
- Bull. 622 b. Tin mining in Alaska, Eakin, 1915
 - i. Iron ore deposits near Nome; placer mining in Seward Peninsula, Eakin, 1915
- Bull. 662 i. Lode mining and prospecting on Seward Peninsula, Mertie; placer mining on Seward Peninsula, Mertie, 1918

- Bull. 692 g. Tin mining in Seward Peninsula; graphite mining in Seward Peninsula, Harrington; the gold and platinum placers of the Kiwalik-Koyuk region, Harrington, 1919
- Bull. 712 g. Mining in northwestern Alaska, Cathcart, 1920
- Bull. 714 f. Mining on Seward Peninsula, Harrington, 1921
- Bull. 722 f. Metalliferous lodes in southern Seward Peninsula, Alaska, Cathcart, 1922
- Bull. 733 Geology of the York Tin deposits, Alaska, Steidtmann, Cathcart, 1922
- Bull. 974 c. Frost action and vegetation patterns on Seward Peninsula, Alaska, Hopkins, Sigafos, 1951
- Bull. 1024 c. Radioactivity investigations at Bar Mountain, Seward Peninsula, Alaska, Killeen, Ordway, 1955
- Bull. 1141 c. Geology of the Imuruk Lake area, Seward Peninsula, Alaska, Hopkins, 1963 (1964)
- Circ. 214 The occurrence of zeunerite at Brooks Mountain, Seward Peninsula, Alaska, West, Mertie, 1952
- Circ. 244 Reconnaissance for radioactive deposits in the vicinity of Teller and Cape Nome, Seward Peninsula, Alaska, 1946-47, White, West, Matzko, 1953
- Circ. 250 Reconnaissance for radioactive deposits in the northeastern part of Seward Peninsula, Alaska, 1945-47 and 1951, Gault, Killeen, West, others, 1953
- Circ. 300 Reconnaissance for radioactive deposits in the Darby Mountains, Seward Peninsula, Alaska, 1948, West, 1953
- Circ. 319 Reconnaissance for Uranium in the Last River area, Alaska, White, West, 1954
- Circ. 479 Beryllium deposits of the western Seward Peninsula, Alaska, Sainsbury, 1963
- Ann. Rept. 20, Part VII b. A reconnaissance in southwestern Alaska in 1898, Spurr, 1899
- Mineral Resources of the United States, calendar year 1900, d. An occurrence of stream tin in the York region, Alaska, Brooks, 1901
- Spec. Pub. Preliminary report on the Cape Nome gold region, Alaska, Schrader, Brooks, 1900
- Spec. Pub. Reconnaissance in the Cape Nome and Norton Bay regions, Alaska in 1900; a reconnaissance of the Cape Nome and adjacent gold fields of Seward Peninsula, Alaska in 1900, Brooks, Richardson, Collier; a reconnaissance in the Norton Bay region, Alaska in 1900, Mendenhall, 1901

Southeastern Alaska

- Prof. Paper 1 Preliminary report on the Ketchikan mining district, Alaska with an introductory sketch of the geology of southeastern Alaska, Brooks, 1902
- Prof. Paper 64 The Yakutat Bay region, Alaska; physiography and glacial geology, Tarr; areal geology, Tarr, Butler, 1909
- Prof. Paper 69 The earthquakes at Yakutat Bay, Alaska in Sept. 1899, Tarr, Martin, with a preface by Gilbert, 1912
- Prof. Paper 87 Geology and are deposits of Copper Mountain and Kasaan Peninsula, Alaska, Wright, 1915
- Prof. Paper 95 h. Notes on the geology of Gravina Island, Alaska, Smith, 1916
- Prof. Paper 120 d. The structure and stratigraphy of Gravina and Revillagigedo islands, Alaska, Chapin, 1919

- Prof. Paper 233 c. Upper Silurian brachiopods from southeastern Alaska, Kirk, Amsden, 1952
- Prof. Paper 251 Geology and mineral deposits of Jumbo Basin, southeastern Alaska, Kennedy, 1953
- Prof. Paper 354 c. Giant Waves in Lituya Bay, Alaska, Miller, 1960
- Prof. Paper 432 Upper Cretaceous (Campanian and Maestrichtian) ammonites from southern Alaska, Jones, 1964
- Bull. 225 Contributions to economic geology, 1903. The Juneau gold belt, Alaska, Spencer; the Porcupine placer mining district, Alaska, Prindle, 1904
- Bull. 236 The Porcupine placer district, Alaska, Wright, 1904
- Bull. 259 (See under Alaska in General.)
- Bull. 284 (See under Alaska in General.)
- Bull. 287 Juneau gold belt, Alaska, Spencer; and a reconnaissance of Admiralty Islands, Alaska, Wright, 1906
- Bull. 314 c. Lode mining in southeastern Alaska, Wright; nonmetalliferous mineral resources of southeastern Alaska, Wright, 1907
- d. Reconnaissance on the Pacific Coast from Yakutat to Alek River
- Bull. 345 b. Lode mining in southeastern Alaska, 1907, Wright; Copper deposits on Kasaan Peninsula, Prince of Wales Island, Wright, Poige; the building stones and materials of southeastern Alaska, Wright, 1908
- Bull. 347 The Ketchikan and Wrangell mining districts, Alaska, Wright, F. E. and C. W., 1908
- Bull. 379 b. Mining in southeastern Alaska, Wright, C. W., 1909
- Bull. 442 c. Mining in southeastern Alaska; occurrence of iron ore near Haines, Knopf; a water power reconnaissance in southeastern Alaska, Hoyt, 1910
- Bull. 446 Geology of the Berners Bay region, Alaska, Knopf, 1911
- Bull. 480 d. Mining in southeastern Alaska, Knopf; the Eagle River region, Knopf, 1911
- Bull. 502 The Eagle River region, southeastern Alaska, Knopf, 1912
- Bull. 503 The Sitka mining district, Alaska, Knopf, 1912
- Bull. 542 b. Marble resources of Ketchikan and Wrangell districts, Burchard, 1913
- d. Mineral deposits at Ellamar district, Capps, Johnson, 1913
- Bull. 592 b. Lode mining in the Ketchikan region, Smith, 1914
- c. Marble resources of the Juneau, Skagway and Sitka districts, Burchard, 1914
- d. A barite deposit near Wrangell, Burchard, 1914
- Bull. 622 c. Mining in the Juneau region, Eakin, 1915
- Bull. 642 b. Mining developments in southeastern Alaska, Chapin, 1916; water power investigations in southeastern Alaska, Canfield, 1916
- Bull. 662 b. Mining developments in the Ketchikan and Wrangell mining districts, Chapin; lode mining in the Juneau gold belt, Eakin; gold placer mining in the Porcupine district, Eakin; water power investigations in southeastern Alaska, Canfield, 1918
- Bull. 682 Marble resources of southeastern Alaska, Burchard, with a section on the geography and geology, Chapin, 1920
- Bull. 692 b. Water power investigations in southeastern Alaska, Canfield; mining developments in the Ketchikan district, Chapin; geology and mineral resources of the west coast of Chichagof Island, Overbeck, 1919
- Bull. 699 The Porcupine gold placer district, Alaska, Eakin, 1919
- Bull. 712 b. Water power investigations in southeastern Alaska, Canfield, 1920
- Bull. 714 b. Lode mining in the Juneau and Ketchikan districts; notes on the Salmon-Unuk River region, Mertie; water power investigations in southeastern Alaska, 1921
- Bull. 722 b. Water power investigations in southeast Alaska, Canfield, 1922
- c. Ore deposits of the Salmon River district, Portland Canal region, Westgate, 1922
- Bull. 739 b. Mineral deposits of the Wrangell district, southeastern Alaska, Buddington, 1923
- Bull. 773 b. Mineral investigations in southeastern Alaska, Buddington, 1925
- Bull. 783 b. Mineral investigations in southeastern Alaska, Buddington, 1926
- Bull. 797 e. Aerial photographic surveys in southeastern Alaska, Sargent, Moffit, 1929
- Bull. 800 Geology and mineral deposits of southeastern Alaska, Buddington, Chapin, 1929
- Bull. 807 Geology of Hyder and vicinity, southeastern Alaska, with a reconnaissance of Chickamin River, Buddington, 1929
- Bull. 824 e. The occurrence of gypsum at Iyoukeen Cove, Chichagof Island, Stewart, 1932
- Bull. 836 c. Surface water supply of southeastern Alaska, 1909-30, Henshaw, 1933
- Bull. 897 d. Nickel content of an Alaskan basic rock, Reed, 1939
- Bull. 929 Geology and ore deposits of the Chichagof mining district, Alaska, Reed, Coats, 1941
- Bull. 936 g. Chromium deposits of Red Bluff Bay and vicinity, Baranof Island, Alaska, Guild, Balsley, 1942
- i. Nickel-copper deposits on the west coast of Chichagof Island, Alaska, Pecora, 1942
- o. Nickel-copper deposit at Funter Bay, Admiralty Island, Alaska, White, 1942
- Bull. 947 b. Malypdenite investigations in southeastern Alaska, Twenhofel, Robinson, Gault, 1946
- c. Nickel investigations in southeastern Alaska, Kennedy, Walton, 1946
- d. Geology and associated mineral deposits of some ultrabasic rock bodies in southeastern Alaska, Kennedy, Walton, 1946
- Bull. 963 a. Some mineral investigations in southeastern Alaska, Twenhofel, Reed, Gates, 1949 (Prince of Wales Island, Chichagof Island, William Henry Bay, Glacier Bay, Bear Creek, Duncan Canal, Kuiu Island)
- c. Garnet deposits near Wrangell, southeastern Alaska, Bressler, 1950

- Bull. 989 b. Gypsum deposits near Iyaukeen Cove, Chichagof Island, southeastern Alaska, Flint, Cobb, 1953
- Bull. 998 a. Zinc-copper deposit at Tracy Arm, Petersburg district, Alaska, Gault, Fellows, 1953
- b. Some zinc-lead deposits of the Wrangell district, Alaska, Gault, Rossman, Flint, Ray, 1953
- c. Some lead-zinc and zinc-copper deposits of the Ketchikan and Wales districts, Alaska, Robinson, Twenhofel, 1953
- Bull. 1024 b. Investigations for radioactive deposits in southeastern Alaska, West, Benson, 1955
- g. Some pegmatite deposits in southeastern Alaska, Sainsbury, 1957
- Bull. 1043 e. Recognition criteria of igneous and metamorphic rocks on aerial photographs of Chichagof and Kruzof Islands, southeastern Alaska, Pomeroy, 1964
- Bull. 1058 Mineral resources of Alaska, 1956, a. Radioactive deposits in southeastern Alaska, Houston, Bates, Velikanje, Wedow, 1958
- b. Geology and ore deposits, Reid Inlet area, Glacier Bay, Alaska, with notes on a mineralized area near Lituya Bay, Rossman, 1958
- c. Geology of Geikie Inlet area, Glacier Bay, Alaska, Seitz, 1959
- h. Geology of part of the Craig C-2 quadrangle and adjoining areas, Prince of Wales Island, southeastern Alaska, Sainsbury, 1961
- Bull. 1090 Iron and copper deposits of Kasaan Peninsula, Prince of Wales Island, southeastern Alaska, Warner, Goddard, others, 1961
- Bull. 1108 b. Geology of the Craig quadrangle, Alaska, Condon, 1961 (1962)
- c. Geology of the Freshwater Bay area, Chichagof Island, Alaska, Loney, Condon, Duto, 1963
- d. Geology of the North Bradfield River iron prospect, southeastern Alaska, MacKevett, Blake, 1963
- Bull. 1121 k. Geology of the eastern part of the Mount Fairweather quadrangle, Glacier Bay, Alaska, Rossman, 1963
- Bull. 1141 o. Reconnaissance geology of Baranof Island, Alaska, Berg, Hinkley, 1963
- Bull. 1154 Geology and ore deposits of the Bakan Mountain uranium-thorium area, southeastern Alaska, MacKevett, 1963 (1964)
- W. S. 372 A water power reconnaissance in south-central Alaska, Ellsworth, Davenport, with a section on southeastern Alaska, Hayt, 1915
- Circ. 147 Geology of proposed Blue Lake dam site and tunnel near Sitka, Alaska, Twenhofel, 1951
- Circ. 184 Reconnaissance for radioactive deposits in south-central Alaska, 1947-49, Maxham, Nelson, 1952
- Circ. 252 Potential Alaskan mineral resources for proposed electrochemical and electrometallurgical industries in the upper Lynn Canal area, Alaska, Twenhofel, 1953
- Circ. 280 Potential industrial sites in the Lynn Canal area, Alaska, Johnson, Twenhofel, 1953
- Ann. Rept. 13, Part II a. Second expedition to Mount St. Elias in 1891, Russell, 1892
- Ann. Rept. 16, Part I c. Glacier Bay and its glaciers, Reid, 1896
- Ann. Rept. 18, Part III a. Reconnaissance of the gold field of southern Alaska, with some notes on general geology, Becker, 1897
- Open File Rept. 208 Magnetite deposits near Klukwan and Haines, southeastern Alaska

Yukon River Basin

- Prof. Paper 10 Reconnaissance from Ft. Hamlin to Kotzebue Sound, Alaska by way of Dall, Kanuti, Allen, and Kowak Rivers, Mendenhall, 1902
- Prof. Paper 20 A reconnaissance in northern Alaska across the Rocky Mountains, along Koyukuk, John, Anaktuvuk and Colville Rivers and the Arctic Coast to Cape Lisbourne in 1901, Schrader, with notes by Peters, 1904
- Prof. Paper 70 The Mount McKinley region, Alaska, Brooks, with descriptions of the igneous rocks and of the Bonfield and Kantishna districts, Prindle, 1911
- Prof. Paper 268 The central Kuskokwim region, Alaska, Cady, Wallace, Hoare, Webber, 1955
- Prof. Paper 293 Quaternary and engineering geology in the central part of the Alaskan Range, Wahrhaftig, Black, 1958
- Bull. 213 Contributions to economic geology; coal resources of the Yukon Basin, Alaska, Collier, 1903
- Bull. 218 The coal resources of the Yukon, Collier, 1903
- Bull. 251 The gold placers of the Fortymile, Birch, and Fairbanks regions, Alaska, Prindle, 1905
- Bull. 259 (See under Alaska in General.)
- Bull. 280 Rampart gold placer region, Alaska, Prindle, Hess, 1906
- Bull. 284 (See under Alaska in General.)
- Bull. 295 The Yukon-Tanana region, Alaska, with description of Circle quadrangle, Prindle, 1906
- Bull. 314 k. Circle precinct, Alaska, Brooks, 1907
- l. Bonfield and Kantishna regions, Alaska, Prindle, 1907
- Bull. 337 The Fairbanks and Rampart quadrangles, Yukon-Tanana region, Alaska, Prindle, with a section on the Rampart placers, Hess; and a paper on the water supply of the Fairbanks region, Covert, 1908
- Bull. 345 d. Occurrence of gold in the Yukon-Tanana region, Prindle; the Fortymile gold placer district, Prindle; water supply of the Fairbanks district 1907, Covert, 1908
- Bull. 375 Fortymile quadrangle, Yukon-Tanana region, Alaska, Prindle, 1909
- Bull. 379 d. Mineral resources of the Nabesna-White River district, Moffit, Knopf, 1909
- e. Fairbanks gold placer region, Prindle, Katz; water supply of the Yukon-Tanana region, Covert, Ellsworth; gold placers of the Ruby Creek district, Maddren; placers of the Gold Hill district, Maddren; gold placers of the Innoko district, Maddren, 1909
- Bull. 410 The Innoko gold placer district, Alaska, with accounts of the central Kuskokwim Valley and the Ruby Creek and Gold Hill placers, Maddren, 1910
- Bull. 417 Mineral resources of the Nabesna-White River district, Alaska, Moffit, Knopf, with a section on the Quaternary, Capps, 1910
- Bull. 442 f. Sketch of the geology of the northeastern part of the Fairbanks quadrangle, Prindle; auriferous quartz veins in the Fairbanks district, Prindle; placer mining in the Yukon-Tanana region, Ellsworth; occurrence of wolframite and cassiterite in the gold placers of Deadwood Creek, Birch Creek district, Johnson; water supply of the Yukon-Tanana region 1909, Ellsworth, 1910
- g. The Koyukuk-Chandalar gold region, Maddren, 1910
- h. Mineral resources of the Nulato-Council region, Smith, Eakin, 1910
- Bull. 449 A geologic reconnaissance in southeastern Seward Peninsula and the Norton Bay-Nulato region, Alaska, Smith, Eakin, 1911
- Bull. 480 g. Placer mining in the Yukon-Tanana region, Ellsworth, Parker; water supply of the Yukon-Tanana region, 1910, Ellsworth, Parker
- h. Mineral resources of the Bonfield region, Capps
- i. Gold placer mining developments in the Innoko-Iditarod region, Maddren, 1911
- Bull. 498 Headwater regions of the Gulkana and Sushitna Rivers, Alaska, with accounts of the Valdez Creek and Chistochina placer districts, Moffit, 1912
- Bull. 501 The Bonfield region, Alaska, Capps, 1912
- Bull. 520 b. Tin resources of Alaska, Hess, 1912
- g. Gold placers between Woodchopper and Fourth of July Creeks, upper Yukon River, Prindle, Mertie
- h. Placer mining in the Fortymile, Eagle, and Seventymile River districts, Porter; water supply of the Fortymile, Seventymile and Eagle districts, Porter; placer mining in the Fairbanks and Circle districts; water supply of the Fairbanks, Salchaket, and Circle districts, Ellsworth, 1912
- i. Rampart and Hot Springs regions, Eakin
- j. The Ruby placer district, Maddren, 1912
- k. Geologic investigations along the Canada-Alaska boundary, Maddren, 1912
- l. The Alutno-Nootak region, Smith, 1912
- Bull. 532 The Koyukuk-Chandalar region, Alaska, Maddren, 1913
- Bull. 535 A geologic reconnaissance of a part of the Rampart quadrangle, Alaska, Eakin, 1913
- Bull. 538 A geologic reconnaissance of Circle quadrangle, Alaska, Prindle, 1913
- Bull. 542 f. Lode mining near Fairbanks, Smith; placer mining in the Yukon-Tanana region, Ellsworth, Davenport; water supply of the Yukon-Tanana region, 1912, Ellsworth, Davenport, 1913
- g. Gold placers of the Ruby district, Eakin; gold placers of the Innoko-Iditarod region, Eakin, 1913
- Bull. 578 The Iditarod-Ruby region, Alaska, Eakin, 1914
- Bull. 592 i. The Chisana placer district, Brooks, 1914
- j. Lode mining near Fairbanks; Chapin, 1914; placer mining in the Yukon-Tanana region, Chapin, 1914; placer mining in the Ruby district, Eakin, 1914
- k. Mineral resources of the Yukon-Koyukuk region, Eakin, 1914
- Bull. 622 b. Tin mining in Alaska, Eakin, 1915
- f. Mineral resources of the Chisana-White River district, Capps, 1915
- g. Mining in the Fairbanks district; mining in the Hot Springs district, Eakin, 1915
- h. Mineral resources of the Lake Clark, Iditarod region, Smith, 1915

- Bull. 630 Chisana-White River district, Alaska, Capps, 1916
- Bull. 631 The Yukon-Koyukuk region, Alaska, Eakin, 1916
- Bull. 642 g. Preliminary report on the Tolovana district, Brooks, 1916
- h. Exploration in the Cosna-Nowitna region, Eakin; mineral resources of the Ruby-Kuskokwim region, Mertie, Harrington, 1916
- Bull. 662 d. The gold placers of the Tolovana district, Mertie, 1918
- e. Mineral resources of the Kantishna region, Capps, 1918
- f. Gold placers of the Anvik-Andreafski region, Harrington, 1918
- g. Lode deposits near the Nenana coal field, Overbeck; gold placers of the Nenana coal field, Modren, 1918
- h. Lode mining in the Fairbanks district, Mertie, 1918
- Bull. 664 The Nenana coal field, Alaska, Martin, 1919
- Bull. 667 The Cosna-Nowitna region, Alaska, Eakin, 1918
- Bull. 683 The Anvik-Andreafski region, Alaska (including the Marshall district), Harrington, 1918
- Bull. 687 The Kantishna region, Alaska, Capps, 1919
- Bull. 692 f. Mining in the Fairbanks district; a molybdenite lode on Healy River; mining in the Hot Springs district, Chapin, 1919; tin deposits of the Ruby district, Chapin, 1919; the gold and platinum placers of the Tolstoi district, Harrington, 1919
- Bull. 712 f. Placer mining in the Tolovana district, Overbeck, 1920
- Bull. 739 c. Recent investigations of petroleum in Alaska (Cold Bay, Iniskin Bay, Anchorage, Nenana coal fields), Capps, Moffit, Brooks, Martin, 1923
- d. The occurrence of metalliferous deposits in the Yukon and Kuskokwim region, Mertie, 1923
- Bull. 754 The Ruby-Kuskokwim region, Alaska, Mertie, Harrington, 1924
- Bull. 755 c. Geology and mineral resources of region traversed by the Alaska Railroad, Capps, 1924
- Bull. 773 e. Geology and gold placers of the Chandalar district, Alaska, Mertie, 1925
- Bull. 783 d. The Nixon Fork country and silver-lead prospects near Ruby, Brown, 1926
- Bull. 792 c. The Toklat-Tonzona River region, Capps, 1927
- Bull. 797 c. Preliminary report on the Sheenjek River district, Mertie, 1929
- Bull. 810 b. The Chandalar-Sheenjek district, Mertie, 1930
- Bull. 813 c. Mining in the Fortymile district, Mertie, 1930
- Bull. 816 Geology of the Eagle-Circle district, Alaska, Mertie, 1930
- Bull. 824 d. Mining in the Circle district, Mertie, 1932
- Bull. 827 A geologic reconnaissance of the Dennison Fork district, Alaska, Mertie, 1931
- Bull. 836 d. The eastern portion of Mt. McKinley National Park, Capps; the Kantishna district, Moffit; mining development in the Tatlanika and Totatlanika basins, Moffit, 1933
- e. The Tatanduk-Nation district, Mertie, 1933
- Bull. 844 b. Mineral investigations in the Alaska Railroad belt, 1931, Capps, 1933
- d. Mineral deposits of Rampart and Hot Springs districts, Alaska, Mertie; placer concentrates of the Rampart and Hot Springs districts, Waters, 1934
- e. Reconnaissance of the upper Koyukuk valley, Marshall, 1934
- Bull. 849 b. Lode deposits of the Fairbanks district, Alaska, Hill, 1933
- f. Lode deposits of Eureka and vicinity, Kantishna district, Alaska, Wells, 1933
- Bull. 857 c. The Curry district, Alaska, Tuck, 1934
- Bull. 864 c. Mineral deposits of the Ruby-Kuskokwim region, Mertie, 1936
- Bull. 868 c. Upper Copper and Tanana rivers, Moffit, 1936
- d. The Kaiyuh Hills, Mertie, 1937
- Bull. 872 The Yukon-Tanana region, Alaska, Mertie, 1937
- Bull. 897 c. Gold placers of the Fortymile, Eagle and Circle districts, Alaska, Mertie, 1938
- Bull. 904 Geology of the Slana-Tok district, Alaska, Moffit, 1938
- Bull. 907 Geology of the Alaska Railroad region, Capps, 1940
- Bull. 917 b. Geology of the Upper Tetling River district, Moffit, 1941
- d. Tertiary deposits of the Eagle-Circle district, Alaska, Mertie, 1942
- Bull. 926 b. Geology of the Gerstle River district, Alaska, with a report on the Black Rapids Glacier, Moffit
- Bull. 933 b. Geology of the Nutzotin Mountains, Alaska, Moffit, with a section on the igneous rocks, Wayland; gold deposits near Nabesna, Wayland, 1943
- d. Reconnaissance of Porcupine Valley, Alaska, Fitzgerald, 1944
- Bull. 936 n. Antimony deposits of the Stampede Creek area, Kantishna district, Alaska, White, 1942
- Bull. 963 e. Coal investigations in south-central Alaska, 1944-46, Barnes, others, with a section on the clay deposits on Healy Creek, Cobb, 1951
- Bull. 989 d. Geology of the eastern part of the Alaska Range and adjacent area, Moffit, 1954
- f. Effect of permafrost on cultivated fields, Fairbanks area, Alaska, Péwé, 1954
- Bull. 1024 i. Tungsten deposits in the Fairbanks district, Alaska, Byers, 1957
- Bull. 1058 i. Toffin belt, Manley Hot Springs district, Alaska, Wayland, 1961
- Bull. 1108 a. Geology of the Mount McKinley quadrangle, Alaska, Reed, 1961
- Bull. 1111 h. Geologic reconnaissance of the Yukon Flats district, Alaska, Williams, 1963
- i. Frost heaving of piles with an example from Fairbanks, Alaska, Péwé, Paige, 1963
- W. S. 218 Water supply investigations in Alaska, 1906-07 (Fairbanks district, Yukon-Tanana region), Henshaw, Covert, 1908
- W. S. 228 Water supply investigations in the Yukon-Tanana region, Alaska, 1907 and 1908 (Fairbanks Circle, and Rampart districts), Covert, Henshaw, 1909
- W. S. 342 Surface water supply of the Yukon-Tanana region, Alaska, Ellsworth, Davenport, 1915

- W. S. 345 f. The discharge of the Yukon River at Eagle, Alaska, Porter, Davenport, 1915
 W. S. 1590 Ground-water resources of the Fairbanks area, Alaska, Cederstrom, 1963
- Circ. 18 Nonmetalliferous deposits in the Alaska Railroad belt, Waring, 1947
 Circ. 185 Reconnaissance for radioactive deposits along the upper Porcupine and lower Coleen Rivers, northwestern Alaska, White, 1952
 Circ. 255 Reconnaissance for radioactive deposits in the lower Yukon-Kuskokwim highlands region, Alaska, 1947, White, Killeen, 1953
 Circ. 279 Reconnaissance for radioactive deposits in the Ruby-Poorman and Nixon Fork districts, west-central Alaska, White, Stevens, 1953
 Circ. 310 Stripping coal deposits on lower Lignite Creek, Nenana coal field, Alaska, Wahrhaftig, Birman, 1954
 Circ. 316 Reconnaissance for radioactive deposits in the Eagle-Nation area, east-central Alaska, 1948, Wedow, 1954
 Circ. 317 Reconnaissance for radioactive deposits in the Manley Hot Springs-Rampart district, east-central Alaska, 1948, Moxham, 1954
 Circ. 328 Reconnaissance for radioactive deposits in the lower Yukon-Kuskokwim region, Alaska, 1952, West, 1954
 Circ. 331 Reconnaissance for radioactive deposits in eastern Interior Alaska, 1946, Wedow, Killeen, others, 1954
 Circ. 332 The Kathleen-Margaret (K-M) copper prospect on the upper Maclaren River, Alaska, Chapman, Saunders, 1954
 Circ. 335 Reconnaissance for radioactive deposits in east-central Alaska, 1949, Wedow, White, others, 1954
 Circ. 348 Reconnaissance for radioactive deposits in eastern Alaska, 1952, Nelson, West, Matzka, 1954
- Ann. Rept. 18, Part III b. Geology of the Yukon gold district, Alaska, Spurr, with an introductory chapter on the history and condition of the district to 1897, Goodrich, 1898
 Ann. Rept. 20, Part VII b. A reconnaissance in southwestern Alaska in 1898, Spurr, 1899
 Part VII c. A reconnaissance from Resurrection Bay to the Tanana River, Alaska in 1898, Mendenhall
 e. A reconnaissance in the White and Tanana river basins, Alaska, in 1898, Brooks
 Ann. Rept. 21, Part II g. A reconnaissance from Pyramid Harbor to Eagle City, Alaska, including a description of the copper deposits of the upper White and Tanana rivers, Brooks, 1900
 Part II h. A reconnaissance of the Chitina River and the Skolai Mountains, Alaska, Rohn
 i. Preliminary report on a reconnaissance along the Chandalar and Koyukuk rivers, Alaska in 1899, Schrader, 1900

PUBLICATIONS OF THE UNITED STATES BUREAU OF MINES

The following publications are listed:

Reports of Investigations (R.I.)
 Information Circulars (I.C.)
 Bulletins (Bull.)

Technical Papers (T.P.)
 Minerals Yearbooks
 Reports of the Mine Inspector for Alaska.

Alaska in General

- R. I. 2103 b. Comparative steaming tests of Alaska lignite and spruce wood, Davis, Hopkins, 1920
 R. I. 3265 Assay of black sands, Hopkins, 1934
 R. I. 4173 Antimony deposits in Alaska, Ebbley, Wright, 1948
 R. I. 4932 Nonmetallic deposits accessible to the Alaska Railroad as possible sources of raw materials for the construction industry, Rutledge, Thorne, Kerns, Mulligan, 1953
 R. I. 5615, Analyses of Tipple and delivered samples of coal (collected during fiscal year 1959) Aresco, Haller, Abernathy, 1960
 R. I. 5620 Field test for beryllium minerals: the Morin fluorescence method, McVay, 1960
 R. I. 5792 Analyses of Tipple and delivered samples of coal (collected during fiscal year 1960) Aresco, Haller, Abernathy, 1961
 R. I. 6002 Some nonmetallic mineral resources for Alaska's construction industry, Warfield, 1962
 R. I. 6054 Performance of tables in cleaning Alaska's coals, Geer, Sokaski, Michael, Jacobsen, 1962
 I. C. 6611 Small-scale placer mining method, Jackson, Knaebel, 1932
 I. C. 7313 Paligarskite--a possible asbestos substitute, Fisher, Thorne, Van Cott, 1945(Alaskan mountain leather)
 I. C. 7379 Alaska's minerals as a basis for industry, Bain, 1946
 I. C. 7679 Names and definitions of regions, districts, and subdistricts in Alaska, Ransome, Kerns, 1954
 I. C. 7926 Methods and Costs at operations using hydraulic and mechanical excavation equipment with non-floating washing plants, Thomas, Cook, Wolff, Kerns, 1959
 I. C. 8017 Summary of mining and petroleum laws of the world, Ely, 1961
 I. C. 8045 Trends in Alaska's mineral industry, Kaufman, 1961
 I. C. 8131 Mercury occurrences in Alaska, Malone, 1962
 WPA 2 (With Works Progress Administration) Small-scale placer mines as a source of gold, employment, and livelihood in 1935, Merrill, Henderson, Kiesling, 1937
 Bull. 36 Alaskan coal problems, Fisher, 1911
 Bull. 142 The mining industry in the Territory of Alaska during the calendar year 1915, Smith, 1917
 Bull. 153 The mining industry in the Territory of Alaska during the calendar year 1916, Smith, 1917
 Bull. 259 Placer mining methods and costs in Alaska, Wimmier, 1927
 T. P. 309 Recent progress in the thawing of frozen gravel in placer mining, Janin, 1922
 T. P. 421 State laws relating to coal mine timbering, Paul, Geyer, 1928
 T. P. 591 Federal placer mining laws and regulations, Johnson; small-scale placer mining methods, Jackson, 1938
 T. P. 668 Low temperature carbonization of Alaskan coal, Selvig, Ode, Davis, 1944
 T. P. 682 Analyses of Alaskan coals, 1946

Minerals Yearbooks from 1933 to present time

Reports of the Mine Inspector for the Territory of Alaska for 1912, 1913, 1914, Smith (Reports from 1914 to 1921, inclusive, were incorporated into annual reports of Director, Bureau of Mines.)

Aleutian Islands

- R. I. 3967 Exploration of Sedanka zinc deposits, Sedanka Island, Alaska, Webber, Moss, Rutledge

Bristol Bay

- R. I. 4065 Mercury deposits of southwestern Alaska, Webber, Bjorklund, Rutledge, Thomas, Wright, 1947
 R. I. 4828 Investigation of Kasna Creek copper prospect, Lake Kontrashibuna, Lake Clark region, Alaska, Warfield, Rutledge, 1951

- R. I. 4890 Investigation of the Millett copper deposit, Iliamna Lake, wouthwestern Alaska, Rutledge, Mulligan, 1952

Cook Inlet - Susitna

- R. I. 2412 Comparative steaming tests of Nenana lignite and Matanuska bituminous coals, Davis, Hopkins, 1922
 R. I. 3784 Moose Creek district of Matanuska coal fields, Alaska, Apell, 1944
 R. I. 3840 Washability characteristics and washing of coals from the Matanuska field of Alaska, Geer, Yancey, 1946
 R. I. 4356 Investigation of Knik Valley chromite deposits, Palmer, Alaska, Bjorklun, Wright, 1948
 R. I. 4360 Investigation of the W. E. Dunkle coal mine, Costello Creek, Chulitna district, Alaska, Rutledge, 1948
 R. I. 4838 Bituminous coal deposits in the vicinity of Eska, Matanuska Valley coal field, Alaska, Jolley, Toenges, Turnbull, 1952
 R. I. 4932 Nonmetallic deposits accessible to the Alaska Railroad as possible sources of raw materials for the construction industry, Rutledge, Thorne, Kerns, Mulligan, 1953
 R. I. 5350 Matanuska coal field near Houston, May, Warfield, 1957
 R. I. 5950 Bituminous coal deposits of the Matanuska coal field, Alaska; central and western parts, Wishbone district, Warfield, 1962

Copper River

- R. I. 3913 Exploration of Spirit Mountain nickel prospect, Canyon Creek, lower Copper River region, Alaska, Pierce, 1946
 R. I. 3940 Exploration of argentiferous lead-copper deposits of the Slana district, Alaska, Thorne, 1946
 R. I. 4986 Investigation of the Copper Bullion claims, Rua Cave, Knight Island, Alaska, Rutledge, 1953
 R. I. 5320 Copper mines and prospects adjacent to Landlocked Bay, Prince William Sound, Alaska, Mihelich, Wells, 1957
 R. I. 5986 Reconnaissance of Alaskan beach sands, eastern Gulf of Alaska, Thomas, Berryhill, 1962

Kenai Peninsula

- R. I. 3885 Exploration of the Red Mountain chromite deposits, Kenai Peninsula, Alaska, Rutledge, 1948
 R. I. 4419 Investigation of Claim Point chromite deposits, Kenai Peninsula, Alaska, Sanford, Cole, 1949
 R. I. 4520 Investigation of coal deposits in south-central Alaska and the Kenai Peninsula, Toenges, Jolley, 1949
 R. I. 4932 Nonmetallic deposits accessible to the Alaska Railroad as possible sources of raw materials for the construction industry, Rutledge, Thorne, Kerns, Mulligan, 1953

Kuskokwim River

- R. I. 4065 Mercury deposits of southwestern Alaska, Webber, Bjorklund, Rutledge, Thomas, Wright, 1947
- R. I. 4361 Investigation of the Rainy Creek mercury prospect, Bethel district, Kuskokwim region, southwestern Alaska, Rutledge, 1948
- R. I. 6141 Trenching and sampling of the rhyolite mercury prospect, Kuskokwim River basin, Alaska, Maloney, 1962
- I. C. 4719 Investigation of mercury deposits, Cinnabar Creek area, Georgetown and Akiak districts, Kuskokwim region, southwestern Alaska, Rutledge, 1950

Northern Alaska

- R. I. 3934 Exploration of coal deposits of the Point Barrow and Wainwright areas, northern Alaska, Sanford, Pierce, 1946
- R. I. 4150 Investigation of coal deposits for local use in the Arctic regions of Alaska, and proposed mine development, Toenges, Jolley, 1947
- R. I. 5447 Analyses of some crude oils from Alaska, McKinney, Garters, Schwartz, 1959
- R. I. 5642 Oil recovery and formation damage in permafrost, Umiat field, Alaska, Baptist, 1960
- R. I. 5706 Well productivity related to drilling muds, Umiat Field, Naval Petroleum Reserve No. 4, Alaska, Gates, Caraway, 1961

Northwestern Alaska

- R. I. 4414 Investigations of the Kobuk River asbestos deposits, Kobuk district, northwestern Alaska,

Seward Peninsula

- R. I. 3902 Investigation of the Lost River tin deposit, Seward Peninsula, Alaska, Heide, 1946
- R. I. 3978 Exploration of Cape Mountain lode tin deposits, Seward Peninsula, Alaska, Heide, Wright, Sanford, 1946
- R. I. 4110 Ward copper deposit, Seward Peninsula, Alaska, Wright, 1947
- R. I. 4345 Churn drilling at Cape Mountain tin placer deposits, Seward Peninsula, Alaska, Heide, Sanford, 1948
- R. I. 5520 Sampling stream gravels for tin near York, Seward Peninsula, Mulligan, 1959
- R. I. 6018 Lead-silver deposits in the Omilak area, Seward Peninsula, Alaska, Mulligan, 1962
- I. C. 7878 Tin placer sampling methods and results, Cape Mountain district, Seward Peninsula, Alaska, Mulligan, Thorne, 1959

Southeastern Alaska

- R. I. 3942 Exploration of the copper-sulphur deposit Khayam and Stumble-on properties, Prince of Wales Island, Alaska, Fosse, 1946
- R. I. 3944 Exploration of Mountain View tungsten deposit, Hyder, Alaska, Erickson, 1946
- R. I. 3950 Exploration of a nickel-copper-cobalt deposit at Funter Bay, Admiralty Island, Alaska, Holt, Moss, 1946
- R. I. 3952 Exploration of the Jumbo Dome basin iron deposit, Prince of Wales Island, southeastern Alaska, Wright, Fosse, 1946
- R. I. 3956 Exploration of Poor Man iron deposit, Kasaan Peninsula, Prince of Wales Island, southeastern Alaska, Holt, Sanford, 1946
- R. I. 4129 Mt. Andrew iron deposit, Kasaan Peninsula, Prince of Wales Island, southeastern Alaska, Wright, Tolonen, 1947
- R. I. 4168 Mirror Harbor nickel deposits, Chichagof Island, Alaska, Traver, 1948
- R. I. 4174 Tungsten deposits in Alaska, Thorne, Muir, Erickson, Thomas, Heide, Wright, 1948
- R. I. 4182 Yakobi Island nickel deposit, Sitka mining district, Alaska, East, Traver, Sanford, Wright, 1948
- R. I. 4349 Diamond drilling at Rush and Brown copper mine, Kasaan Bay, Prince of Wales Island, southeastern Alaska, Holt, Shepard, Thorne, Tolonen, Fosse, 1948
- R. I. 4358 Investigation of Salt Chuck mine, Kasaan Peninsula, Prince of Wales Island, southeastern Alaska, Holt, Shepard, Thorne, Tolonen, Fosse, 1948
- R. I. 4373 Investigation of Tolstoi Mountain iron deposits, Kasaan Peninsula, Prince of Wales Island, southeastern Alaska, Erickson, 1948
- R. I. 4421 Investigation of Muir Inlet or Nunatak molybdenum deposits, Glacier Bay, southeastern Alaska, Sanford, Apell, Rutledge, 1949
- R. I. 4669 Investigation of Taylor Creek lead-zinc deposit, Kupreanof Island, Petersburg, Alaska, Kerns, 1950
- R. I. 4984 Concentration Klukwan, Alaska magnetite ore, Wells, Thorne, 1953
- R. I. 5195 Studies of the Snettisham magnetite deposit, southeastern Alaska, Thorne, Wells, 1956
- R. I. 5312 Beneficiation of iron-copper ores from Kasaan Peninsula, Prince of Wales Island, Alaska, Wells, Ersamer, Sterling, 1957
- R. I. 6043 Recovery of mineral values in cupriferous and nickelliferous pyrrhotite, Fursman, 1962
- I. C. 6168 Mining methods and costs, Alaska Juneau Gold Mining Company, Juneau, Alaska, Bradley, 1929
- I. C. 7488 Southeastern Alaska's mineral industry, Kaufman, 1958

Yukon River

- R. I. 2412 Comparative steaming tests of Nenana lignite and Matanuska bituminous coals, Davis, Hopkins, 1922
- R. I. 3951 Exploration of leasing block No. 28 in the Nenana coal field, Alaska, Marstrander, Apell, Rutledge, Hulbert, 1946
- R. I. 4121 Investigation of the Mount Eielson zinc-lead deposits, Mt. McKinley National Park, Alaska, Muir, Thomas, Sanford, 1947
- R. I. 4174 Tungsten deposits in Alaska, Thorne, Muir, Erickson, Thomas, Heide, Wright, 1948
- R. I. 4322 Investigation of the Morelock Creek tin placer deposits, Ft. Gibbon district, Alaska, Thomas, Wright, 1948
- R. I. 4323 Investigation of the Tozimoran Creek tin placer deposits, Thomas, Wright, 1948
- R. I. 4346 Sampling methods and results at the Sullivan Creek tin placer deposits, Manley Hot Springs, Tofty, Alaska, Thorne, Wright, 1948
- R. I. 4932 Nonmetallic deposits accessible to the Alaska Railroad as possible sources of raw materials for the construction industry, Rutledge, Thorne, Kerns, Mulligan, 1953
- R. I. 5373 Tin bearing placer deposits near Tofty, Hot Springs district, central Alaska, Thomas, 1957
- R. I. 5991 Investigation of mercury-antimony deposits near Flat, Yukon River region, Alaska, Moloney, 1962

BUREAU OF LAND MANAGEMENT PUBLICATIONS

- Information Bulletin No. 2 Alaska - Information relative to the disposal and leasing of public lands in Alaska, 1948
 Questions and Answers - Land settlement in Alaska by veterans of World War II
 Circ. No. 1941 - Lode and placer mining regulations. Part 185, Title 43 of the Code of Federal regulations, Nov. 1, 1955
 Mineral Patents - Information relative to the procedure for obtaining patent to a mining claim, Nov. 1947
 Circ. No. 1278 - Information in regard to mining claims in the Public Domain
 Circ. No. 2037 - Oil and gas leases, part 192, Title 43, 1960
 Oil and Gas Leasing in Alaska.
 What is the new Multiple use law?

UNPUBLISHED THESES AND PAPERS DEALING WITH ALASKA MINING ON FILE
AT THE UNIVERSITY OF ALASKA LIBRARY

- Comparison of power units in Fairbanks district, Lundell, no date
 Economics of mine plant interruptions, Mathews, no date
 Treatment of complex silver-lead-zinc ore (Kantishna), Morgan, 1926
 Gold quartz veins on northern flank of Pedro Dome, Fairbanks district, Loftus, 1927
 Treatment of complex silver-lead-zinc ore (Kantishna), McCarty, 1927
 Plans and specifications for proposed mines building, Alaska Agricultural College and School of Mines, Lingo, 1927
 Investigation-Use of magnetometer in determining placer concentrations, Smith, 1927
 Treatment of lead-silver-zinc ore (Taku River), Tripp, 1928
 Factors affecting production of antimony in Interior Alaska, Wheeler, Schoeser, 1928
 Evolution of placer mining methods, Alaska, Parker, 1929
 Application of geomagnetics to placer exploration, Boswell, 1929
 Metallurgical test of ore from the Prometheus lode, Ester Dome, Fairbanks district, Doheny, 1930
 Accompanying investigation of gold bearing quartz veins of Ester Dome, McCombe, 1931
 Investigation of gold bearing quartz veins of Ester Dome, McCombe, Augustine, 1931
 Ore occurrence and ore-dressing problems of Liberty Bell mine, Strandberg, Mize, 1931
 Preliminary tests of clay deposits adjacent to the Alaska Railroad, Beeler, 1931
 The cyanide leaching of cuprous gold and silver bearing tailings of the Nixon Fork district, Alaska, Kubon, Burns, 1932
 A report on cyanidation tests on auriferous flotation concentrate and tailings from Liberty Bell mine, Wilcox, 1932
 Girwood mining district, Redman, 1932
 Preparation of frozen alluvium of interior Alaska for gold dredging, Roberts, 1932
 Nuka Bay mining district, Heath, 1932
 Metallurgical treatment of ore from the Bigelow property, Landis, 1933
 Microscopic study of quartz, Moyer, 1933
 Gold dredging in Alaska, Herbert, 1934
 Gold quartz veins on the north flank of Pedro Dome, Spencer, O'Neill, 1934
 Notes - Pleistocene and recent geology of Fairbanks district, Dorsh, 1934
 Treatment of Mohawk tailings, Bowman, Thomas, 1935
 Gold content and treatment methods of river and black sand, Schulz, 1935
 Placer prospect on Seward Peninsula, Shallit, 1936
 An investigation of the marble at Fox, Alaska, Henton, Wickstrom, 1936
 Geological aspects of coal occurrence at Yanert, Alaska, Fowler, 1936
 Cyanide process, Maddox, 1937
 Water hammer in pipe lines, Dalton, 1937
 Petroleum situation in Alaska, Saxon, 1937
 Water disposal at the Alaska Juneau Gold Mines, Beistline, 1937
 Copper in Alaska, Osburne, 1937
 Birch Creek schist, Lyman, 1937
 Mining methods at the Alaska Juneau Mine, K. Anderson, 1937
 Application of geo-resistivity to placer exploration, T. Mathews, 1938
 Placer mining in Alaska, T. Mathews, 1938
 Study of platinum group minerals, Saxon, 1939
 Examination of the Harry W. Woods mine, Twin Creek, Fairbanks district, Beistline, 1939
 Report on the Blue Bird mine, T. Kukkola, 1939
 Geology and dressing of gold and silver ore of Homestake mine, Wolf Creek, Fairbanks district, Hall, 1940
 Mineralogy applied to treatment of typical ore from Fairbanks district, Dickey, 1940
 Placer mining methods and costs, Circle district, R. Mathews, 1940
 Study of world tin fields, with special reference to the Manley Hot Springs deposits, Downing, 1940
 History of placer mining in Alaska, Hildebrandt, 1941
 Gold ore of the Independence mine, Willow Creek district, Alaska, E. Anderson, 1941
 Exploration of placer deposits in Alaska, Picotte, 1941
 Recovery of values in mill tailings in Fairbanks district, O'Neill, 1941
 Placer deposits in the upper Kougarak, Seward Peninsula, Alaska, Shallit, 1941

- Proposed placer mining courses to be added to the University of Alaska curriculum, Boswell, 1942
 Placer valuation and dredge screen testing, Daheny, 1942
 Dredge sampling of placer ground and dredge cleanup procedure, Beistline, 1947
 Gravity water supply for placer mines, Hilchey, 1947
 The platinum deposits of Goodnews Bay, Alaska, Spencer, 1948
 Planning and operation of hydraulic stripping plants, Johnston, 1948
 Scheelite deposits of the Fairbanks district, Alaska, Lefond, 1948
 Dredge metallurgy, Redmond, 1948
 Relations of structure to mineral deposition of the Grant mine, Ester Dame, Alaska, Sandvik, Hersey, 1951
 Geology of the Fossil Creek area, White Mountains, Alaska, Church, 1961
 Geology of the Fossil Creek area, White Mountains, Alaska, Durfee, 1961
 Bedrock geology and ore deposits of the Pedro Dome area, Fairbanks Mining District, Alaska, Brown, 1963
 Bedrock geology of the Rainbow Mountain area, Alaska Range, Alaska, 1964

TERRITORIAL AND STATE PUBLICATIONS

Department of Labor

General Safety Code, Henry A. Benson, Commissioner, 1949

Territorial Department of Mines and Division of Mines and Minerals

- Reports of the Territorial mine inspectors and Commissioners of mines from 1912 to present
 Strategic mineral occurrences in interior Alaska, Joesting, 1942
 Supplement to above, Joesting, 1943
 Mineral occurrences other than gold deposits in northwestern Alaska, Anderson, 1944
 Prospecting in Alaska, Steward, 1944 (Revised 1949)
 Industrial minerals as a field for prospecting in Alaska, including a glossary of elements and minerals, Glover, 1945 (Revised 1946)
 Asbestos and jade occurrences in the Kobuk River region, Alaska, Anderson, 1945
 Some high calcium limestone deposits in southeastern Alaska, Roehm, 1946
 Rights of Canadians in Alaska under the mining laws; I. C. No. 2, 1953
 Alaska Uranium Information; I. C. No. 4, 1955
 Compulsory assessment work affidavits; I. C. No. 7, 1957
 Report on preliminary investigation of the Kings River area limestone deposits, Anchorage quadrangle, Alaska, Jasper, Mihelich, 1961
 Report on the Mespelt Mine of Strandberg Mines, Inc., Nixon Fork district, Medfra quadrangle, Alaska, Jasper, 1961
 Alaska's new mining law for State lands, Williams, 1961
 Geology and ore deposits of Alaska, Herreid, 1961
 A preliminary map of the bedrock geology of the Fairbanks mining district, Alaska, Forbes, Brown, 1961
 Mineral industry consultants available for work in Alaska; I. C. No. 8, 1962
 List of Department of Mines and Minerals publications; I. C. No. 11, 1962
 Hand placer mining methods; I. C. No. 3, 1962
 Skin diving for gold in Alaska; I. C. No. 10, 1962
 The mineral industry of the Kenai-Cook Inlet-Susitna regions, Race, 1962
 Services of the Division of Mines and Minerals; I. C. No. 12, 1962
 Dangers in old mine openings; I. C. No. 13, 1962
 Dealers in Alaskan rocks and minerals; I. C. No. 9, 1963

Proper claim staking in Alaska; I. C. No. 1, 1963
 Alaskan prospecting information; I. C. No. 6, 1963
 Geologic report 3 Geology of the Portage Creek-Susitna River area, Richter, 1963
 General Alaskan mineral information; I. C. No. 5, 1964
 See Annual Reports of Division of Mines and Minerals for additions to this list.

Alaska Resources Development Board

Federal land policy and its effect on development of Alaska, Riley, 1948	An economic study of Haines, Alaska, Cooley, 1953
Northwestern Alaska, Browne, 1949	Fairbanks, Alaska, Cooley, 1954
The Sitka district, Browne, 1950	Estimate of Alaska population, 1955
The Cordova district, Browne, 1951	Alaska passenger traffic survey, 1956
Fort Yukon, Alaska, Shimkin, 1951	Biennial reports
Alaska's dollar shortage, edited by Sundborg, 1951	

BRIEF LIST OF BOOKS ON PROSPECTING AND MINING

(See also references at end of each chapter.)

American Geological Institute, Glossary of geology and related sciences, 1957
 Boericke, W. F., Prospecting and Operating small gold placers, 2nd ed., John Wiley and Sons, Inc., New York, 1942
 British Columbia Dept. of Mines, Geology applied to prospecting, Vancouver, B. C.
 Canada Dept. of Mines and Tech. Services, Geological Survey of Canada, Prospecting in Canada, Ottawa, Ont., 1957
 Same: G29 Mining textbooklets (not sold separately.) Ottawa, Ont., 1945
 1. Geology and Mineralogy
 2. Prospecting in Canada
 3. Practical mining
 4. Business of prospecting and mining
 Fay, Albert H., A Glossary of the mining and mineral industry: U. S. Bureau of Mines Bull. 95, 1920
 Gardner, E. D., Johnson, C. H., Placer mining in Western United States, Part 1, U. S. Bureau of Mines Ic 6786, 1934
 Goodwin, W. L., The prospectors' handbook, 4th Ed., National Business Publications Ltd., Garden-wall, Quebec, 1956
 Hoover, H. H., Principles of Mining, McGraw-Hill Book Co., New York, 1909
 Manitoba Dept. of Mines and Natural Resources, A guide for prospectors in Manitoba, Winnipeg, 1952
 Peele, Robert., Mining Engineers' Handbook, 3rd Ed., John Wiley and Sons, Inc., New York, 1941
 Savage, Eros M., Prospecting for gold and silver, McGraw-Hill Book Co., Inc., New York, 1934
 Spurr, J. E., Geology applied to mining, McGraw-Hill Book Co., Inc., New York, 1904
 von Bernewitz, M. W. (revised by Chellson, Harry C.) Handbook for prospectors and operators of small mines, 4th Ed., McGraw-Hill Book Co., Inc., New York, 1943
 Wilson, E. B., Hydraulic and placer mining, 3rd Ed., John Wiley and Sons, Inc., New York, 1918

Chapter 20

ADDENDUM

INTRODUCTION

In this chapter the author proposes to describe certain changes that have occurred in various fields considered under the chapter headings in the first edition. Those subjects in which changes have occurred that are significant enough to describe are taken up chapter by chapter in the order they appeared in the first edition.

Certainly great advances in geology and geological concepts have taken place in recent years, yet it would not be feasible to add much to the chapters on geology that constitute Part I, especially in a book intended for prospectors. Exceptions are Chapters 1 and 5. Geology, one of the oldest of the sciences, because of its complex nature, has been a data-gathering and descriptive one. Attempts to fit the data into comprehensive theories have been successful only to a small extent. Because such attempts at generalizing have lately met with a little more success, both on a world wide basis and for the more restricted areas of Alaska, a brief description of two such ideas is given here.

CHAPTER 1

In Chapter 1 there is a brief mention of vertical and lateral crustal movements and of the possible fundamental causes for these movements. Since the discovery of such a fundamental cause would give geology a somewhat more quantitative basis such as underlies many other sciences, any data tending to do this are of extreme importance. Since the writing of the first edition, discoveries in the oceans indicate that the ocean floors are moving from a central source area toward the continents on the ocean's margins. The material that moves away from this mid-ocean ridge is replaced from the mantle below; at the margins of the oceans, material is carried under the continents. It must be emphasized that as yet no mechanism is known for causing this movement, although convection currents within the mantle are often invoked. What is important to all phases of geology is that with the discovery of these regular movements, which apparently have been operative far back into earth history, the movement of continents, with buckling, folding, thrusting, faulting, uplift, and extension, begins to make more sense. Indeed, crustal unrest, especially near the margins of continents, is more to be expected than not. The many areas where the ocean floor spreading hypothesis does not explain all of the observed facts, does not detract from it as a valuable beginning.

CHAPTER 5

Accelerated mapping by the U. S. Geological Survey and the State Division of Mines and Geology (note new name) has given a wealth of descriptive data to help understand the geologic makeup of Alaska. Here no attempt will be made to report on the new mapping; such a report could only be made in a work devoted exclusively to the geology of Alaska. However, new concepts about the structure of Alaska, and generalizations about the history, make it possible to reach a more comprehensive picture, and very briefly they are described here.

Tectonics deals with the deformation of the crust and the structural forms that result from that deformation. A tectonic map of Alaska indicates an orderly arcuate succession of structures and tectonic provinces that are extensions of north-south structures in the western United States and Canada. In Alaska these curve northwest, then west, and finally southwest toward Asia. These structural elements, from the Gulf Coast to the Brooks Range, comprise the Alaskan part of the Cordillera. The Cordillera in North America is the complex of mountain ranges and intermountain basins and lowlands that we think of as roughly comprising the western mountains. It is widest at about 35°N latitude, where it extends for 1000 miles from the Front Range of the Rockies in Colorado to the Coast Ranges of California. To the east, in the central part of the continent, the crust is stable. This stable interior is represented in Alaska only by the relatively narrow portion north of the Brooks Range. Hence most of Alaska lies in the North American Cordillera.

Such a portion of the crust that has undergone uplift and depression is called a mobile belt. Portions of the North American Cordilleran mobile belt have been rela-

tively stable for several million years, while others are in almost daily motion. Two catastrophic uplifts within 60 years along the south side of the St. Elias Range aggregated more than 100 feet.

The diastrophism that has produced mobile belts has occurred at different times along different belts (see page 85). The various elements of the western Cordillera have also been formed at different times, but generally the crustal movements that formed them lasted from Jurassic time to the present.

It is possible to discern a certain regularity and pattern to the movements in a mobile belt that greatly help in studying, for example, the Alaskan structures. This regularity has been termed the tectonic cycle and its chief proponents have been Russian geologists; many geologists refer to the concepts as "vertical tectonics."

The cycle starts with the early geosynclinal stage, with increased mobility over a considerable width, with alternating areas of uplift and wider intervening downwarps which receive sediments. Deep fracturing, with accompanying extrusions and intrusions of basic magma accompanies this stage. The elevation of the uplifted areas was not extreme. In Alaska this first stage began in middle Devonian time and continued to late Triassic. This crustal unrest is also observed in the Cordillera farther south, where it is known in Nevada as the Antler Orogeny.

The next phase in the tectonic cycle is called the late geosynclinal stage, in which uplift predominates over downwarping. There is more folding than in the early stage, and the linear uplifts generally take place at the sites of former downwarps or geosynclines. These uplifted early geosynclines are called central uplifts. As they rise, troughs develop on either side, which receive sediments from the central uplifts. These sediments lap up onto the central uplifts, and are called clastic wedges. The whole process is accompanied by folding, intrusion of granitic rocks, and metamorphism. Because the former geosynclines are now elevated, while the intervening geanticlines are depressed, it is called inversion.

In Alaska the late geosynclinal stage began in Middle Jurassic and lasted until early Tertiary time. It is the greatest single geologic event in the history of Alaska, or of the entire Cordillera, for it is responsible for the basic structures of the present mountains and intermontane basins; not however, for their present elevations and relief which are due to later uplifts and downwarps. Although it may be referred to as an event, inversion took place at different times at different places. All of Alaska, except for the Arctic Coastal Plain, is occupied by Mesozoic inversion structures, which is a different way of saying that it lies in the Cordillera.

The third and last phase in the cycle is called the young platform stage. Although some folding still went on, block faulting became more important, and block uplifts and depressions were superimposed on the earlier folded structures. At the same time there was deep fracturing, with intrusions along the fractures. In Alaska the stage has lasted from early Tertiary time to the present. The Mesozoic clastic wedges were folded and uplifted in early Tertiary time and then in late Tertiary were eroded to surfaces of low relief. It was on this Tertiary surface that the present drainage pattern developed. Although some parts of the surface have been slowly uplifted, other parts have been downfaulted in Tertiary and Pleistocene times to form the great flats of Alaska.

On page 78 the term "geosyncline" was defined. The concept of the tectonic cycle makes an understanding of geosynclines much more important. From the description of the elements of the western continent already given we can generalize a mobile belt bordering a stable continental platform. The Great Plains in the United States and the Arctic Coastal Plain in Alaska are part of the platform. That part of the mobile belt nearest the platform is called a miogeosyncline; the deformation here is less intense than farther out, and the sediments deposited in it are more like those of the shelf: limestones, quartz sandstones and shales. These are sediments from relatively stable areas deposited in relatively shallow water.

Outside of the miogeosyncline is the eugeosyncline, a rapidly subsiding trough into which are poured poorly sorted dark sediments, much of them of volcanic origin. It is in these types of sediments that the basic rocks are intruded and extruded during the geosynclinal stages as described above. Volcanic activity, either below or above water, is characteristic of eugeosynclines.

Because of this difference in type of rocks formed on the platforms, in miogeosynclines, and in eugeosynclines, it is possible from studying present day rocks to reconstruct the environment of deposition. It has been determined that in early Paleozoic time the sequence: platform - miogeosyncline - eugeosyncline extended across southern Alaska, with the platform on the north and the eugeosyncline on the south. During Paleozoic time, this sequence moved northward, so that by Triassic time the edge of the platform was in northern Alaska and the miogeosyncline somewhere south of the Brooks Range.

There are several implications in considering the history of Alaska from the standpoint of the tectonic cycle. On page 83 the evidence was given for considering the Birch Creek

Schist to be early or middle Precambrian. While this is probably true, mapping in other parts of Alaska has thrown doubt on the whole idea of determining the age of a rock by the degree of metamorphism. If the geosynclines of the early geosynclinal stage were uplifted during inversion in the late geosynclinal stage, then the rocks that we see in the centers of the central uplifts are those which were buried deepest during the earlier stage. Deep burial could have produced metamorphism in the rocks now in the centers of the central uplifts, while the unmetamorphosed Paleozoic rocks on the flanks of the central uplifts actually are older. An interesting aspect of this concept is that along the edges of the central uplifts there may be shear zones along which magma and mineralizing solutions could rise.

The search for oil that has occupied much attention in recent years has shed light upon the characteristics of the Mesozoic clastic wedges. Although these clastic wedges consist chiefly of unmetamorphosed sedimentary rocks, most of these rocks are either of low permeability, or are too deformed to yield oil. Hence most of them, even though they contain tremendous volumes of unmetamorphosed sedimentary rocks, can yield little oil. The oil production in the Arctic is coming from Paleozoic rocks near the Arctic Coast, where the Paleozoics are covered by about 3000 feet of Mesozoic and later rocks. Further south on the axis of the Colville geosyncline, the Mesozoic rocks are 15,000 feet thick. (The Colville geosyncline is the northernmost Mesozoic clastic wedge.)

In the Mesozoic basin that underlies Cook Inlet (the Matanuska geosyncline), continued subsidence in Tertiary time allowed as much as 15,000 feet of Tertiary sediments to accumulate over the Mesozoic rocks. Oil and gas have accumulated in the permeable zones near the base of the Tertiary rocks.

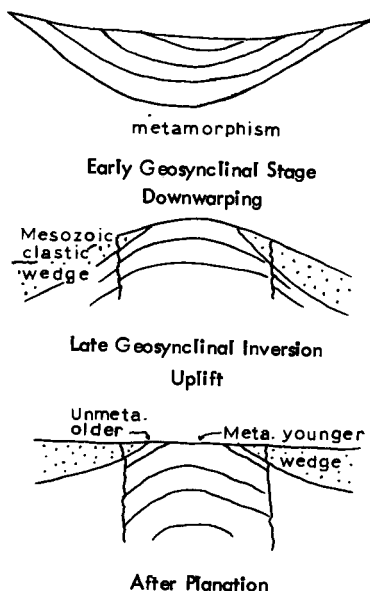


Figure 20-1 - Early and Late Geosynclinal Stage

CHAPTER 8

Chapter 8, entitled "Background", touches lightly on such subjects as financing prospecting, what kind of man makes a prospector, the present status of prospecting and mining in Alaska, and a brief history.

During the past ten years some significant changes have taken place which affect each one of these subjects. Our technological civilization is moving at an ever increasing pace, requiring ever increasing amounts of minerals and in turn providing ever advancing techniques and training for finding them. All of this has created interest in exploration. In addition, since the second World War, the world has known unparalleled prosperity, which, with inflation, has tended to depress the gold mining industry until recently, but which has created great demand for all other mineral commodities. The tremendous demand is finally bringing home to people in the mineral industry the fact that the world contains only a finite amount of minerals, and that they had better get out and look for reserves. This realization, coupled with the development of equipment, such as helicopters, which has allowed the roadless expanses of Alaska to be quickly traversed, is inducing more companies to invest money in Alaskan prospecting. Another factor which is changing the atmosphere in Alaska is the growth of Japanese industry. People are already speaking of "the Pacific basin", around which are distributed areas that use natural resources and those that supply natural resources. Alaska is favorably situated geographically to supply raw materials to Japan.

The discovery of a major, though perhaps at present somewhat low grade copper deposit on Ruby Creek on the Kobuk (the Bornite deposit) was the first major discovery of a metallic deposit since the Goodnews Bay platinum discovery in the 1920's. Gradually people are beginning to believe that more mineral deposits can and will be discovered in Alaska. Finally, the great discoveries of oil in the Cook Inlet region and more recently (Spring, 1968) along the Arctic Coast have provided great impetus to exploration for both oil and minerals.

All of this has tended to change the economic outlook for exploration in Alaska. At the risk of dating this edition of the Handbook, it may be said that we are now in a period of optimism, but considerably more subdued than that of the first years of the century. Inevitably also it is more of an era of big companies. Consider point 2, page 173, "Because of improved standards of living, modern man is unused to hardships —". Techniques that have come into common use since that was written have made the statement meaningless providing the prospector can afford continuous helicopter support. Since only large companies can afford this support, it still has some meaning for the individual prospector, and hence is a factor hindering prospecting. This is but a small example of the advantages in this modern day that go with bigness.

It should here be noted that point 10, page 173, no longer is true. All prospecting costs can now be directly deducted as expenses for income tax purposes. (See section on mining law later in this chapter.)

Methods of financing prospecting were briefly analyzed in Chapter 8. These methods are still available, and little can be added. However, another comment on the advantages of bigness is appropriate here. Producing mining companies can count as expenses 15% of production, and oil companies 27 1/2% (again see section on mining law for circumstances that alter this). This is the depletion allowance. It is analogous to depreciation of equipment, and allows the mining company to say that it will plow back 15% of its production into finding new deposits in order to stay in business. This gives the company, so long as it is producing minerals, the funds to prospect. Private individuals have no such sources. The money spent on prospecting by them must come from private accumulated capital. It is no wonder that most prospecting today is done by mining companies.

Finally, six years of history have gone by since the first edition of this Handbook appeared. The listing of historical events ends on page 179 with 1963, the purchase of the Ruby Creek deposit by Bear Creek Mining Company. Since that time the property has been transferred to the Kennecott Copper Corporation, and been turned back; it is now under development.

The greatest event in recent years is the discovery in 1968 and 1969 of very large reserves of oil at Prudhoe Bay on the Arctic Coast. Either a pipeline to the Gulf of Alaska or combined tanker-icebreakers through the Northwest Passage, are contemplated.

Later in this chapter, under mining law, recent changes in leasing regulations will be described. Here it must be mentioned that there are strong feelings among people who have never prospected, who believe that the mining laws are no longer serving the best interests of the country. On January 18, 1969, the Secretary of the Interior published in the Federal Register certain regulations that govern open pit mining on Federal leasing lands. At present, several bills are before the Federal Congress which would put restrictions on surface mining, the more extreme of these, including land of any ownership. The idea has also been expressed that all minerals, including metallics, should be leased.

These ideas, many of which have already been translated into regulations having the power of law, will certainly influence the "Public Land Law Review Commission" which is currently gathering information on which to base recommendations for changes in the land laws.

After World War II, the mining industry of Western Canada was in somewhat the position it is at present in Alaska. The placers were shut down, and the few lode mines operating had been known for a long time. During the last twenty years, a tremendous resurgence has taken place in Canada. Canadian authorities attribute this to liberal laws that provide incentives to risk capital, and Alaskan observers have no reason to doubt this. The NORTH Commission (Northern Operations of Rail Transportation and Highways), established in 1967, is a State supported commission which is trying to promote transportation in the north. This is an example of the thinking of one segment of the population which favors industrializing wherever possible.

There are therefore, at present, opposing views in Alaska, one seeking to place restrictions on mining, the other to provide incentives.

CHAPTER 9

This chapter, entitled "General Prospecting", attempts to describe some of the factors to be considered both before going into the field and during the first reconnaissance. On page 181 there is a discussion of metal prices and other factors that influence a choice of area and of commodities for which to prospect. Some of the figures quoted have caused confusion. These figures are approximate, and were intended as illustrations of things to consider in prospecting for base metals. One thing that was not pointed out is that the price received for base metal concentrates at the smelters are lower than those that are obtained simply by multiplying the price of a metal times the percentage of the metal in an ore. All large base metal mining companies operate their own smelters, and in some cases, their own fabricating plants. Thus they can make a profit on the mining, on the smelting, and on the fabricating. If a prospector should find a base metal mine, his best course of action would be to sell it to a large company.

The discussion of transportation and remoteness in Chapter 9 is still valid. There appears to be some cause for optimism that the transportation situation will improve. The NORTH Commission, already mentioned, is trying to promote an extension of the Alaska Railroad, and in the winter of 1968-1969, a winter trail to the Arctic was built with State funds. Still, the problem of transportation of base metals from isolated areas remains. Kennecott Copper Corporation's mine at Bornite must either ship via the Kobuk River, a seasonal operation, or build a railroad. Obviously one mine cannot support a railroad, but if more mines are found, it might become economically feasible. Further, if the Bornite deposit had not been near a river, no alternatives would exist.

In Chapter 9, it was pointed out that gold, as an object of prospecting, is enhanced in remote areas because it has such a high value that it costs hardly anything to ship. Inflation has steadily eroded this preferred position until in 1968 very little gold mining was conducted. In 1968 the two tier system was instituted. Under this system, the United States Mint no longer buys gold; it is sold to certain licensed buyers. Since the commercial price is now (1969) about \$42 against the mint price of \$35, the situation of gold, at least for the present, is improved. Small amounts of untreated placer gold may also be sold for jewelry purposes at higher prices.

Another point that may need reconsideration is the statement on page 181 "— if a mine has been shut down, there is always a reason." This is still as true as ever, but because most of Alaska's idle mines have been shut down for decades, conditions may be sufficiently changed to justify another look at them.

CHAPTERS 12 and 13

These chapters describe techniques for hand methods of open-cutting, crosscutting, shaft sinking and drifting on placer deposits. The techniques are still the best hand methods. There is little to add here except that modern materials and equipment may be applied when available, e.g. plastic sheets may be used to line dams and reservoirs. A small bulldozer can speed up drain digging or crosscutting on the surface, and on some benches where thawed dry ground may be found; a small backhoe can be used to dig prospect pits. The material from such a pit must be sluiced, and the hole must be measured to determine its volume, just as with a shaft. In thawed ground, either wet or dry, a small clamshell or orange peel type of digger or a small gas driven shovel can speed up shaft sinking. In wet ground of course, some provision for casing the hole must be made.

CHAPTER 14

This chapter gives a lengthy description of churn drilling as it applies to placer prospecting. It is still applicable, and for careful evaluation, the methods of calculating volumes and values are still the ones used.

In water well drilling, and of course in oil well drilling, the trend has been to use rotary drills, which are much faster, although more expensive, than cable tool drills. Until now, rotary drills have been little used for placer prospecting, but there appear to be no reasons why they should not be so used, especially in frozen ground. In fact, almost any kind of drill could be used in frozen ground except an auger.

There are at least two drills besides churn drills now being used in placer prospecting. One, the Becker hammer drill, uses a double walled pipe with a toothed bit at the bottom. This pipe is driven by a diesel powered anvil and acts as combined bit and casing. An inside pipe is kept a short distance behind (above) the bit, and air or water is pumped down the outside, returning the sample up the inside pipe. Rates up to 100 feet per hour are achieved. This drill has been used on offshore drilling through the ice at Nome. It appears to be a very good placer prospect drill, but because of its size (42,000 lbs. truck mounted) it could be used only on large, well-financed operations.

Another drill which should be adaptable to placer prospecting is the Overburden drilling equipment of Atlas Copco. This is an air driven drill that consists of a toothed rotating casing with a hammer drill inside. The drill and casing advance simultaneously. Samples are collected by flushing or by introducing special sampling equipment. This equipment weighs about 5500 lbs., less the compressor.

Undoubtedly, other drills could be adapted, but it is doubtful if any of them will give the accuracy of the churn drill in thawed saturated gravel. However, as noted in Chapter 14, most placer drilling has been done to block out and delineate the pay on creeks already known to have gold. It is doubtful if any new, previously unknown, creek has been discovered for at least 30 years. What the placer mining industry needs is lightweight equipment that can be taken across country and will drill 20 to 30 feet in a matter of two or three hours. Such a drill, even if it could drive only a 2 or 2 1/2 inch casing, would give enough information so that the prospector could say whether there is gold or no gold present. The accuracy could then be checked with a larger drill or a shaft.

Research in drilling placer deposits with small rotary or hammer drills is needed. For the past twenty years the economic outlook for gold has been such that research by mining companies was not justified. Inflation was steadily depressing the buying power of gold, and no end appeared in sight. With a higher price for gold, at least for the present, interest in placer prospecting may revive.

CHAPTER 15

The opening statement in Chapter 15 indicates that geophysical methods have not been applied to any great extent in Alaska. This statement is no longer strictly true; several properties have now been explored by various types of geophysical prospecting techniques. Of the types described in Chapter 15, only magnetic, self-potential, electromagnetic, radiometric, and ultraviolet have much direct application in mineral prospecting (a new method, induced polarization, or I. P. has also lately come into use).

Seismic

Within the last few years lightweight seismic equipment costing from \$1500 to \$5000 has been developed. Most of such equipment can be used only with the refraction method, in which seismic waves travel to an interface, along the interface, and up to the geophone. Although under favorable conditions the interpretation of refraction data is quite simple, the presence at depth of layers that transmit seismic waves at slower velocity than the overlying material causes the method to fail. In addition, the method measures the rate of transmission of seismic waves in a medium. This physical property is not of particular use in detecting ore deposits. If a situation exists where either this physical property, or depth to bedrock, or to a different rock, is useful, then the method may be profitably applied. Manufacturers of lightweight seismic equipment issue explicit instructions for obtaining and interpreting refraction data in simple situations, but like any other indirect method, the interpretation is sometimes difficult or impossible.

Gravitational

The discussion of the gravitational method on page 267 is extremely sketchy. There are four necessary corrections besides the regional change and drift correction mentioned. Although these are fairly simple to apply, they are laborious and require precise measurements of elevation, latitudinal distances and terrain. Disseminated metals probably would not provide enough difference in density to allow the method to be used. Again, as with the seismic method, there may be special conditions under which it is the best method. A barite deposit, for example, could be quickly outlined by its density, while magnetic or electrical measurements would prove nothing. The cost of a small gravimeter, however, is great considering its limited application to ore prospecting.

Magnetic

The magnetic method is probably the most versatile and useful all-around method available. The discussion starting on page 268 is sufficiently detailed so that useful magnetic measurements could be made using them as a guide. They are in fact, too detailed; they were written for use with the magnetic balance type of magnetometer. Modern instruments make the measurement and reduction of magnetic data much easier. There are two such instruments, based on different principles. The fluxgate magnetometer utilizes two high permeability cores in which cyclic fields are induced by an alternating current carried in windings; the cores are driven to saturation and wound in such a way that the fields oppose each other. The earth's magnetic field aids one and opposes the other, and hence saturation is reached at different times in the two cores. Voltages are induced in secondary windings on the two cores, and the resultant of these two is proportional to the magnetic field strength. Another model of fluxgate magnetometer uses only one coil.

Either type requires only coarse levelling and can be hand held.

The second kind of magnetometer, the nuclear precession type, depends upon the fact that most atomic nuclei have a magnetic moment, and tend to align themselves either parallel or perpendicular to an external magnetic field. A strong magnetic field is applied to the nuclei (hydrogen in water) orienting them. When the field is removed, the magnetic moment precesses back to its original value and direction. The frequency of precession, which depends upon the magnetic field strength, is measured electronically. Nuclear precession magnetometers are built with direct read-out devices and need not be levelled. They can operate in any position, even upside down.

Since the nuclear precession magnetometer need not be levelled, it lends itself to the measurement of magnetic gradient. A reading is taken several feet above the ground, with the sensing head on a stick, and another one at ground level. The difference in the readings, divided by the separation distance, is the vertical magnetic gradient. A plot of vertical gradient sometimes gives more detailed information than one of total field strength.

Electrical

Electrical methods, namely self-potential and resistivity, have undergone little change since the first edition of the Handbook was published. Again, new instrumentation is perhaps the greatest change. Miniaturization of electronic equipment has made possible the manufacture of lightweight instruments. Plans are now available, for example, for a self-potential device which reads potentials directly without the necessity of balancing a potentiometer (see M.I.R.L. bibliography). It is still necessary, however, to use porous pots for electrodes to avoid polarization effects.

It should be pointed out that the diagram on page 273 shows only one electrode configuration, the Lee. When the central potential electrode is eliminated, it is called the Wenner. Two other configurations are the Schlumberger and the Dipole. All of these have different geometry and hence different formulas for apparent resistivity.

Electromagnetic

Electromagnetic methods received only a very brief mention in the first edition. The reason for this was that little was known of it in the United States although well-known in Sweden and Canada, even though the method probably ranks just behind the magnetic method in applicability to ore prospecting.

The last paragraph in the section, on page 275, states, "Perhaps the fastest and most satisfactory use for this method is the search for buried conductors at shallow depth with horizontal loops. The mine detector, used to locate land mines by the army, is an application of this method." The statement is no longer true. The method has great application in prospecting for massive sulfides.

Although there are several methods, basically they depend upon having a transmitter (a coil or straight wire through which an alternating current is passing) and a receiver in which the transmitted electromagnetic field induces a voltage. If there is a conductor in the ground between the transmitter and receiver, another field is generated which interacts with the primary field to create a distortion.

The simplest apparatus for determining the amount of this distortion consists of a transmitting loop and a receiving loop which are both hand held. The receiving loop has a tilt-indicating device so that deviations from the vertical can be read. The receiving loop is oriented to a null signal and the tilt is read. Two lines are laid out so that points opposite each other on the lines can be successively occupied, transmitter on one line, receiver on the other. As the pair moves along the lines, a change in the tilt from one side of the vertical to the other indicates that a conducting body has been passed (see Fig. 20-2). This tilt angle method has been used since the early days of geophysical prospecting and is still used. It has, however, serious limitations of sensitivity.

A more sensitive method is the phase angle method. In this method that component of the secondary field induced in the conductor which is in phase with the primary field, is compared with that component which is 90° out of phase. The greater the ratio of the in-phase component to the 90° out of phase component, the better the conductor. However, the frequency of the primary field and the position of the equipment with respect to the conductor also influence these.

There are several arrangements utilizing the phase angle method. Probably the most popular one utilizes a moving transmitter attached by wire to a moving receiver through a compensator. The transmitter and receiver are moved as a pair, keeping the separation distance constant with the cable. The compensator allows the in-phase (real) and the 90° out of phase (imaginary) components to be measured by comparing them with a reference voltage from the source, using the connecting cable.

Since the property measured by the electromagnetic method is electrical conductivity, salt water, saturated fissures, graphite shale, and other worthless material and fea-

tures will be detected as well as metallic deposits.

Radiometric, ultraviolet light and the beryllium meter will receive no further discussion other than that given in the first edition.

Induced Polarization

This last geophysical method was not even mentioned in the first edition. This method, induced polarization (I. P.) has been widely used in recent years in prospecting for disseminated sulfide deposits. It is probably the most costly of ground geophysical methods, and the equipment also is expensive. I. P. works on the principle that grains of mineral or clay particles become polarized by a current passing through the ground. After the current has flowed for a short time, the voltage builds up to a maximum, and just as with the resistivity method, the voltage drop due to the current flow can be measured between any two points in the vicinity of the current electrodes. It is found that after the current is shut off, the voltage between the two points does not drop to zero immediately, but decays more or less slowly, depending on the number of conducting particles. The situation is analogous to that of a multi-plate condenser which can store a charge due to a voltage impressed across the plates, and discharge it if the charging voltage is removed and the circuit closed. Since the conducting particles cause the ground to act like a condenser, the magnitude of an alternating current passing through the ground increases with frequency. These two features, chargeability and increase of conductivity with frequency, are used in I. P., the first in the time domain method and the second in the frequency domain method. In the time domain method, some electrode configuration borrowed from the resistivity method is used, and the voltage between the potential electrodes is measured after a direct current has flowed for a short time. This is the "normal potential". The current is interrupted, and the residual voltage across the electrodes is measured a short time later. The I. P. effect then equals:

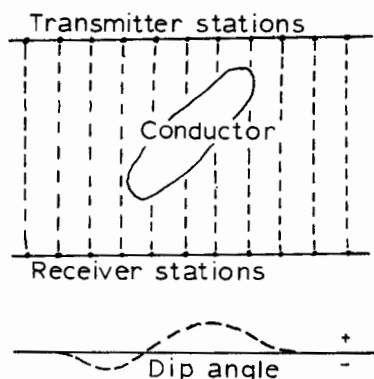


Figure 20-2 - Parallel Line Method of Dip Angle Determination

Another measure of the effect is the percentage of the normal voltage represented by the residual voltage, or percent polarization. It can be seen that the current and the normal voltage allow the apparent resistivity to be computed, since the geometry of the electrode layout is known (see page 274).

In the frequency domain method, the apparent resistivity at a very low frequency, usually 0.1 cycle per second, is measured, and then at 10 c.p.s. The frequency effect of I. P. is defined as:

$$F.E. = \frac{\text{Residual voltage in millivolts}}{\text{normal voltage in volts}} = \frac{\text{Resis. at 0.1 cps} - \text{Resis. at 10 cps}}{\text{Resis. at 10 cps}}$$

Another measure of frequency effect is the metal factor:

$$M.F. = \frac{\text{Resis. at 0.1 cps} - \text{Resis. at 10 cps}}{\text{Resis. at 0.1 cps} \times \text{Resis. at 10 cps}} \times 2\pi \times 10^5$$

Since an I. P. survey always involves the measurement of apparent resistivity, at least one authority has questioned the advantage of I. P. over resistivity. It appears, however that enough information from case histories now has been assembled to indicate the advantage of I. P. in studying disseminated sulfide deposits of the porphyry copper type.

In the third paragraph on page 280, the question is asked "—what method could be used to outline a large lowgrade copper deposit, averaging less than 1% copper?" Apparently induced polarization can provide at least a partial answer.

In Table 15-1 on page 279 Induced Polarization should be added to the direct methods for any metallic deposits of magmatic, contact, or hydrothermal origin. Also "mechanical" should be added to "residual".

Geochemical

A method of geochemical prospecting that combines water sampling and soil sampling is sediment sampling. Samples of stream sediments are taken from the surface, alongside the water. These sediments when analyzed, allow drainage basins to be prospected in a manner analogous to water sampling, or if analyses can be made for specific elements, to mineralogical prospecting (see page 285).

Atomic absorption analyses, which can be done by private firms in and out of Alaska, as well as by State and Federal agencies, now provide rapid means of quantitatively determining trace amounts of specific elements. The cost of these analyses is low enough so that the methods are entirely feasible, considering the cost of obtaining the samples.

A recent publication by the U. S. Geological Survey describes a combination technique (Circ. 592, 1968). Samples from streams draining the San Juan Mountains of Colorado were panned down until the light colored material had disappeared. If the concentrate thus obtained weighed more than 50 grams, it was split to 50 grams. This sample was ground to 80 or 100 mesh and about 15 grams of this was sampled by spatula. Samples smaller than 50 grams were not split before grinding. Samples of less than 15 grams were analyzed in their entirety. The pulverized 15 gram samples were fire assayed, the beads dissolved in acid, and the gold content determined by atomic absorption spectroscopy.

Streams draining areas of 1) no known gold deposits, 2) those containing few prospects, and 3) those containing several mines and prospects, were sampled. It was found that in group 1, gold was not present in quantities sufficient to be detected (0.02 ppm). In group 2, gold contents ranged from 0.03 to 5.1, but usually were around 0.1 to 1 ppm. In group 3, gold contents ranged up to 98 ppm with many around 30, 40, and 50 ppm. These were roughly converted to gold contents for the field samples. The highest content so obtained was 0.3, or about \$0.30 per ton. Obviously, this is a sensitive test, and the authors of the paper believe it possible to determine by several samples whether a further search of the drainage area for gold is justified.

CHAPTER 16

Although there are many techniques, especially modern ones, that are not covered in Chapter 16, it is not thought feasible to discuss new ones here.

CHAPTER 17

Transportation

In Chapter 17, methods of transportation are considered by areas of Alaska; here the methods are described without regard to region, but with the understanding that they are applicable more in some areas than in others.

Everything appearing in Chapter 17 is still pertinent; it is of course realized that improvements and changes have been made to the old methods. For example, on page 322 the DC-3 and C-46 airplanes were mentioned. Although these are still large planes considering the amount of freight involved in a small prospecting operation, much larger ones are now available.

Also, improvements have been made in ground and water transportation. Whereas fifteen years ago only the military weasel was in general use, today several reliable tracked vehicles are available; the Bombardier, Ranger, and Thiokol Imp to name a few. If any kind of road or trail is accessible, four-wheel drive trucks and power scooters may be practical. Conditions in most of Alaska, however, preclude their use. Air-driven boats have also been developed for shallow water.

Two new vehicles, however, are of greater importance. The first and most important is the helicopter. All that has been said about air transportation is still valid, but under certain circumstances the helicopter may be more economical; the following factors should be considered in deciding whether to use airplanes or helicopters. The cost per hour for a helicopter is several times higher than for a comparable fixed wing airplane and hence if a long ferrying flight with the helicopter is necessary, the cost very rapidly becomes prohibitive. For this reason it is almost essential that the prospector try to choose a time when a helicopter is in the region. Suppose that a prospector with two men can fly to a lake, from where it would take two days to pack to the prospecting site. Not counting his own time, he has to pay four man-days wages without accomplishing any useful work. In addition, he is severely limited on weight. If a helicopter were obtainable at the nearest airstrip, it is quite possible that it would be more economical to use it. If the helicopter flight was 50 miles, it almost certainly would be; if 100 miles, it would be necessary to check the costs carefully; if the helicopter would have a ferrying flight of 300 miles, the cost probably would be prohibitive.

Other factors which must be considered are these: in Chapter 17, considerable space was devoted to describing how an outfit can be landed by ski plane in early spring and hauled to the base of operations by two or three dogs. This usually is in early April, and often nothing much can be done until June. This means that the prospector must waste, or only partly use, 2 1/2 months, or cache his outfit and come back later, necessitating two trips. Here the advantage of the helicopter is apparent. Also, any time that objects weighing more than about 60 pounds must be moved by packing after the snow has left, the use of a helicopter is advisable.

Even though the helicopter has given the prospector more flexibility, it is still necessary to make arrangements beforehand for a time for it to return for him. Anyone who has done this with an airplane knows how immobile this leaves him at the end of the season. Often it is better to simply walk out. Bearing in mind the precautions about rafting rivers given on page 329, the improved transportation brought about by the helicopter makes it possible under certain circumstances to take in a small rubber raft, which would provide a way out down a nearby river. Rubber rafts are more stable than small pole rafts, and hence, safer. On rivers that do not have rapids, it may be possible to use a crude canoe or boat framed with willows and covered with water-proofed canvas. Five or six yards of 6 foot wide canvas, a gallon of oil paint, and some galvanized nails are all the extra material needed to build such a boat.

The second development of importance after the helicopter, that is rapidly changing transportation is the snow machine or snowmobile. There are about a dozen models made, ranging in price from \$700 to \$2000. It is an absolute certainty that these machines will replace large dog teams as winter freighters. Their advantages are exactly those which caused the farmers and ranchers of America to adopt mechanical tractors, replacing draft horses. Their disadvantages are similar to those which force the ranchers to maintain saddle horses for some work.

For the single prospector who needs mobility and transportation capable of moving small loads in summer and winter, two dogs, able to pull in winter and pack in summer, as well as to provide companionship, still have their place. Cheap nutritious modern dog-feed is available which allows the dogs to be cared for easily and with less expense than in the days when only rice and fish were attainable. Here the advantages of dogs ends, however.

Snow machines are reported to be able to handle four times their weight, and they weigh from 275 to 600 pounds. Their speed is easily three to four times that of the dogs, and their range at least four times depending on trail conditions. The machines break their own trails, eliminating much snowshoeing, and make a wide enough trail so that the old bugaboo of the freighter, the 600 pound load off the trail and tipped over, is almost eliminated. The smaller of the machines can be loaded into a single engined airplane by two men. For the prospector, whose winter travel is restricted to a localized area, and who would have to bring in feed for dogs anyway, the extra weight in gasoline, parts, and tools does not impose much added expense. It should be noted here, that because the snowmobile is a recent development and because winter prospecting is at a low ebb, very little use has been made of them in prospecting. Widespread experience gained in other fields, however, indicates that if used as a serious means of locomotion, and not abused, snowmobiles will provide cheap, dependable winter transportation, midway between the dog team and the caterpillar tractor, and for many purposes superior to both.

Because of its speed and because it is subject to mechanical failure, the snowmobile can get a person into serious trouble. The story is told of a man who walked a week to get home from a snowmobile excursion. Using a snowmobile in cold weather imposes all of the common sense precautions that dog team travel did and does. The following safety tips are from the *Alaska Sportsman* for November, 1967, and were written by Elmer F. Brisbois, then president of the Anchorage Motor Musers Club.

- "1. Dress adequately. Not only for present weather but potential weather.
2. Take a first aid kit, arctic survival gear (including arctic sleeping bag), adequate food for several days, hatchet or small axe, matches, snow goggles, face masks, rope, and snowshoes.
3. Travel with two or more machines whenever possible and be sure to file a 'flight plan'. Let someone know where you are going and when you expect to return.
4. In populated areas use common sense. Stop before crossing roads. When pulling toboggans or sleds use tow bar instead of ropes to prevent sled from overtaking or tipping the machine. Drive at reasonable speed so control can be maintained.
5. When traveling on rivers or streams be particularly cautious. Flow of water may cause thin spots or holes in the ice. When crossing lakes avoid overflow areas.
6. Remember the chill factor. This must be considered when moving at moderate to speeds. Prevent frostbite or snow-blindness and use face masks and sunglasses."

The caterpillar tractor has of course been a mainstay of transportation in Alaska since it first appeared. In winter, when the ground is frozen, it has little trouble with bogging

down, but after the winter frost has thawed, tractors are easily buried. There are several factors which affect this: first, a tractor intended chiefly for tractive power in summer should be chosen with pressure per square inch of track very much in mind. It is possible to get wide tracks for this, but these tracks may interfere with the bulldozer blade. For pulling sleds on a road or trail, of course, one may dispense with the blade, but this is not a good policy when going across country, because the blade is needed for filling holes, crossing streams and smoothing grades.

The second precaution is to develop a sense of what ground will or will not hold up the tractor. Generally, watercourses in muck or moss are soft, and any place in the tundra that supports a lush growth of green grass should be avoided. A chain saw and axe should be carried at all times and corduroy logs should be laid ahead of the tractor about two to three feet apart, if the ground appears soft. If a go-devil is being towed, the distance between tractor and go-devil should be lengthened with a choker or chain before the tractor starts across. After the tractor crosses, the go-devil is connected by a longer chain. This has two purposes; first the tractor can negotiate soft ground easier without the load, and second, if it should be necessary to back out, the go-devil will not be in the way.

If, in spite of careful watching, the tractor bogs down, it is important to stop it before it gets deeper. There are a number of techniques used to extricate a tractor. One is to chain or cable one log across the tracks, or a shorter log to each track. As the logs are drawn under the tractor, it lifts itself out. If the tractor has a hydraulic blade, cordwood is laid under the blade, and the hydraulic rams are used to raise the front end. Large chunks of cordwood are laid under the front ends of the tracks, and the weight of the tractor is let down on them. The process is repeated until the front ends of the tracks are in a position for the tractor to crawl out on the wood. The tractor is then walked out of the soft ground on the corduroy.

If the tractor does not have a hydraulic blade, the job is more difficult. Sometimes simply waiting a day allows the mud to stiffen up (some soils become more liquid when agitated). Sometimes throwing cordwood beneath the tracks will enable the tractor to crawl out. Finally, it may be necessary to dig or bring in a pump for hydraulicking, or to jack.

Food

Several people have suggested that a recipe for sourdough be included in this addendum. Sourdough can be used in camp in two ways. It contains natural yeast, and when mixed with milk or water, salt, shortening, and enough flour to make it stiff, it can be kneaded into bread and allowed to rise. In the early days of the century, yeast was hard to obtain in Alaska and hence sourdough bread was made extensively. The other way in which sourdough is used is to take advantage of its acid content. Until about 1900, baking powder was unknown, or at least not in common use. Baking powder is a mixture of baking soda and cream of tartar, which, when wet, generates carbon dioxide gas. The acid of the sourdough plus ordinary baking soda produces the same gas.

The raw sourdough starter, is made by mixing a paste of flour and water and a small amount of starter obtained from someone else, or about a teaspoon of dry baker's yeast. (There is sourdough in Alaska that was brought over the Klondike Trail before 1898.) After the starter has set for several days (10-14 depending on room temperature) in a warm place, and become sour, without, however, separating to form a watery phase, it is ready to use. When sour enough, about half of the starter (approximately 1 1/2 cups) is poured into a bowl, and the following ingredients added and stirred into it:

- 3 tablespoons sugar
- 1 teaspoon salt
- 1/2 teaspoon baking soda
- 4 tablespoons melted shortening
- 1 or 2 eggs

This is cooked into hotcakes or waffles, and can be altered to suit the taste by adding more soda if too sour, or more shortening if a lighter hotcake is desired. If used every day, about one half of the starter is saved each morning, and flour and water added at night. If used less often, less than half is saved. If used only once a week, only perhaps one seventh is saved, so that it does not get too sour; however, there is nothing worse than hotcakes made with dough not sour enough. In early days the prospectors went to great lengths to keep the dough at souring temperature. On the trail the sourdough pot was kept near the stove at night and in a fur lined box on the sled during the day.

CHAPTER 18

For many years, Henry Roden's book *Alaska Mining Laws* furnished factual information for prospectors. Now, *Alaska Mining Law Manual* by Charles F. Herbert fulfills the same function. For this reason, Chapter 18, which is now somewhat out of date, will not be rewritten. Instead, at the end of this section is a listing of comments and corrections to specific statements in Chapter 18. The author is indebted to George R. Schmidt for these corrections, and they are reproduced here almost verbatim with his permission. Another reason for not expending much time in rewriting is that the Land Law Review Commission is to make its recommendations in 1970, after which Federal mining and leasing laws probably will be changed.

Other changes, not specifically codified in statutes, are taking place. The author stated on page 343 that the Government did not care what steps a prospector took to safeguard his investment of time and money, at least until patent was applied for. Until 1946, there was no Bureau of Land Management; one of its predecessors, the Land Office, was chiefly concerned with disposing of the public domain, not with managing it. Gradually a new philosophy has crept in: the land is to be classified as to its greatest potential value and surface rights are not granted with mineral rights. There is also an increasing tendency to check on the prospector to see if he is meeting the requirements of the mining law, to require more reclamation of mined lands, to place restrictions on methods of mining and to supervise mining operations and any other activities that disturb the surface of the land.

Another subject which requires mention is the recently (January 1969) enacted Department of Interior regulations for surface exploration, mining and reclamation of lands.

These regulations apply to surface mining of Federal Leasing Act minerals: potash, soda, phosphate, and the "common varieties of building stones", but not to oil and gas. They in general call for: 1) application for permit to explore, 2) technical examination of the property to be explored, 3) denial or approval of application, 4) filing of detailed and comprehensive plans of exploration, mining and reclamation, 5) posting of bond to ensure adherence to terms of lease, 6) reports and inspections.

The Alaska State Division of Lands has periodically proposed similar regulations for all prospecting and mining on State lands. There is support in Congress for the enactment of similar laws for all surface mining in the United States, no matter on what type of lands, and presumably no matter what are the recommendations of the Public Land Law Review Commission.

The prospector in Alaska is operating under at least twelve sets of rules: 1) Federal mining law, 2) Federal mining leasing laws, 3) Federal oil leasing laws, 4) Federal coal leasing laws, 5) Federal asphalt and oil shale laws, 6) State mining law applied to Federal lands, and 7) State offshore lands. Five more sets of laws are State laws corresponding to 1, 2, 3, 4, and 5; they are applied to State lands. It should be noted that corresponding Federal and State laws are quite similar. Five and six, Federal and State laws applying to locatable minerals on Federal lands make up one set of rules and may be considered as a unit. In addition to these laws, Indian Reservations, e.g. Venetie, may have their own rules.

State and Federal laws and regulations are mixed in together in Chapter 18, and the balance of this section is devoted to briefly attempting to organize them a little better. Details can be found in the previously mentioned book by Herbert.

Following are listed specific points in the Alaskan State laws.

State Laws on Federal Lands

The location notice is placed on the northeast stake, not the discovery post. However on lode claims, the Bureau of Land Management requires that a discovery monument be established containing the names of the claim and the locators and the direction and distance to a numbered claim post. Center lines for lode claims need not be staked.

State law makes it mandatory to record assessment work; and it also further requires that a claim owner who has not recorded his assessment work, in order to regain title, must wait one year and then restake the claim.

Placer association claims staked for anything else but precious metals may contain a maximum of 160 acres as under the pre-Wickersham Act (1912) days, provided that there is at least one locator per 20 acres. The maximum size of a precious metal placer claim may not be more than 40 acres, with at least one locator per 20 acres. The precious metal association placer claim requires \$100 worth of annual assessment work for each 20 acres or portion thereof, but any other placer association requires only \$100 worth for the whole association claim.

State Laws on State Lands

All tidelands and offshore lands for a distance of three nautical miles offshore, as well as lands beneath navigable waters, and beneath bays between headlands not more than 24 miles apart, belong to the State.

The State may select lands to the extent of 102,500,000 acres within 25 years after January 3, 1959. The State must retail title to all minerals.

All mining claims, either placer or lode, are of 40 acres with the maximum dimension 1320 feet.

There are no extralateral rights on State lands.

Other provisions of State laws are listed in George Schmidt's comments at the end of this section, and in Alaskan Mining Law Manual.

The following are comments and corrections to Chapter 18, by George R. Schmidt:

"The following suggested changes are listed by subsection and paragraph:

Introduction, #2:

The Bureau of Land Management is concerned with mining claims not only when patent is applied for, but also in those exceptional cases where they may conflict with a federal program or where the mining claim may have been located for nonmining purposes. Those instances have been rare in Alaska; in some of the western states they have been more common.

History, #1:

Federal mining law applicable in Alaska is no longer modified, except by State law.

Laws Pertaining to Both Lode and Placer, #1:

Excepted minerals are 'oil and gas, potassium, sodium, phosphate, oil shale, native asphalt, solid and semisolid bitumen and bituminous rock including oil-impregnated rock or sands from which oil is recoverable '(43 CFR 2100.0-2). Also, in Louisiana and New Mexico, sulphur. When the listed minerals are found on public domain, they are leasable.

Deposits of common varieties of sand stone, gravel, pumice, pumicite, cinders, and clay found on the public land may be purchased, except that governmental units and nonprofit corporations and associations may secure free use permits. Petrified wood may be secured under the free use provisions, although for individual collectors no permit is necessary. (43 CFR 3610)

In addition to the School and University sections and the University selection, Congress provided, in the act of July 28, 1956, that the Territory (now State) might select within 10 years 1,000,000 acres to further its Mental Health program. The Alaska Statehood Act of July 7, 1958, provided also for the selection within 25 years, after January 3, 1959, of 102,550,000 acres from the public lands for general purposes, and 400,000 acres each from national forests and the public domain for community purposes. The reserved school and university sections must have been surveyed as of the statehood date in order to pass to the State. The Statehood Act, by implication, repealed the requirement of nonmineral character for selections made after January 3, 1959.

Acquiring Mineral Claims, #6:

The locator of a placer claim does not acquire any rights to a known lode. If a lode should be discovered after patent is issued, he does acquire the lode.

#13 (last paragraph):

An association placer claim (more than one locator) located on public domain needs only one discovery and, if for a base metal or mineral, requires only \$100 per year assessment work. A precious metal or mineral placer claim may not exceed 40 acres and does require \$200 per year assessment work.

Assessment Work, #1

If the claims are contiguous, the work may be done on one claim provided it can be shown to benefit all of the claims.

#4

Survey of a claim, or maintenance of claim boundaries, are not creditable towards assessment work. See 304. S.C.A. 28, Part VIII, Annual Labor or Work.

" #6:

Federal law requires performance of assessment work. Filing affidavits of work is a matter of State law.

Laws Pertaining to Lodes, #2:

Federal regulations (not law) require a stake or monument at the point of discovery to which is attached the notice of location. Recent State Law (since publication of the Handbook) requires posting at the northeast corner of the claim.

#3:

There is no longer a Federal or State requirement for monumentation of the lode line, or vein. Minimum number of stakes, therefore, is five.

Laws Pertaining to Placers, #1:

There is no longer any limitation of the number of placer claims which may be located. Under State law, an association placer claim for precious metals or minerals, however, may not contain more than 40 acres no matter how many locators. There must, of course, be two locators for such a claim exceeding 20 acres.

#3:

An association claim for precious metals or minerals must not exceed 40 acres. An association claim for base metals or minerals may include up to 160 acres, provided there is a bona fide locator for each 20 acres or fraction thereof.

#7 (last paragraph):

The number of claims which may be located is not limited. The statement concerning power of attorney is correct, although it applies only to precious metal or mineral claims.

Millsites, #1:

A millsite may now be located in connection with a placer claim (act of March 18, 1960).

#2:

A millsite may be contiguous to a lode or placer claim, but must not be contiguous to the lode, or, presumably, the placer. The essential ingredients are that the land be nonmineral in character, and that the site be used for operations in connection with the mining claim.

Water Rights, #6 (last paragraph):

Notification of the State Division of Lands may help preserve rights under the new State Water Code.

Patenting, #2:

Each claim must have been improved by at least \$500 worth of labor or improvements. Simply expending \$500 may not be enough.

#4:

Since there are no counties in Alaska, none can be named. If the claim lies within one of the organized boroughs (comparable to counties in most other states), it must be named.

#6:

In addition, the application must show the claimant is a citizen of the United States, and must be accompanied by a copy of the notice to be published. The Bureau of Land Management will assist in preparing the notice. In Alaska, there must also be a corroborated statement that no portion of the land is occupied or reserved by the United States so as to prevent its acquisition under the mining laws; that the land is unoccupied, unimproved and unappropriated by any person, other than the applicant, claiming the land.

" #7:

The 60 day publication period does not end until the close of the 4th day after the date of the 9th issue.

#8:

An adverse claim must be filed during the publication period. The act permitting an additional eight months was repealed by the act of September 12, 1961. Suit for adverse claims must be filed within 30 days. The same act repealed the law permitting 60 days.

#9:

Price to be paid is \$5.00 per acre, or fraction thereof, for lode claims and for millsites used in connection with lode claims or as custom millsites; \$2.50 per acre, or fraction thereof, for placer claims or millsites used in connection with placer claims.

Leasing Regulations:

Leasable minerals were listed under 'Laws Pertaining to Both Lode and Placer'. Gravel and other common variety minerals may be purchased, usually by the cubic yard or ton.

Coal, #1:

The 'Alaska Coal Leasing Act' was repealed by the act of September 9, 1959. Coal in Alaska is now leased under the provisions of the Mineral Leasing Act of 1920 as in other states.

Maximum acreage which may be under coal lease is now 46,080 acres in one state. See act of August 31, 1964.

#11:

Prospecting permits are issued for two year periods, with the possibility upon showing of need for a single two year extension.

Oil and Gas, #2:

Maximum area which may be held under oil and gas lease is 246,080 acres in each state except Alaska. Alaska has been divided into two leasing districts. One may hold leases for not more than 300,000 acres in each district.

#3:

Applications for lease on surveyed lands must describe legal subdivisions. If the lands are covered by protracted surveys (paper surveys) the application must describe protracted sections. If otherwise unsurveyed, the application must describe the area by a metes and bounds description. The government does not survey oil and gas leases, either on the ground or on paper.

#4:

Competitive leases are issued for five years and so long thereafter as oil and gas is produced commercially. Noncompetitive leases are issued for ten years.

Annual rental for competitive leases is \$2.00 per acre, on noncompetitive leases, it is 50 cents per acre. If within the structure of a producing field the rental is \$2.00 per acre.

The \$1,000 bond required in connection with noncompetitive leases must be posted prior to drilling operations. The bond in connection with a competitive lease is not less than \$1,000 and not more than \$10,000.

#6:

The Secretary of the Interior approves unitization of leases. In connection with this, the Geological Survey offers its recommendations.

#7:

In Alaska, one lessee may hold interest in no more than 300,000 acres in each of the two leasing districts, of which not more than 200,000 acres may be held under option in each leasing district.

" Forms:

This should specify that forms for mining notices, etc., may be available from local printers. Forms used in connection with mineral leases are available from the Bureau of Land Management or the Division of Lands, as is appropriate."

CHAPTER 19

There is little to add to this chapter, except to indicate new roads that have been built.

In addition to the roads and railroads listed on pages 368 - 369, the following new ones have been built. On the Kenai Peninsula, the road from the Sterling highway to Satalmatof has been extended to Nikishka. A road connects Livengood with the system at Manley Hot Springs, joining the system at Glen. A road extends from Fairbanks via Ester and Nenana to Healy. This road will soon join a road north from Anchorage. When a short segment south of Healy is finished, a road will parallel the Alaska Railroad from Seward to Fairbanks. There is a road from Nome to Teller.

In the winter of 1968 - 1969, just past, a winter road was built from Livengood to Bettles Field to Anaktuvuk Pass to Sagwon in the Arctic. This was built to allow truck freight to move from Fairbanks to the developing oil fields. It is not known whether it will be rebuilt each year.

In 1967, the Governor set up the NORTH Commission consisting of leaders in the field of transportation. The purpose of the Commission is to study all phases of surface transportation in the north, and to work for the development of such transportation. At present it is concentrating on an extension of the Alaska Railroad to Bornite on the Kobuk, and to the Arctic oil fields.

Since the discovery of very large reserves of oil at Prudhoe Bay on the Arctic Coast on the Beaufort Sea, a 48 inch pipeline to Fairbanks and the Gulf of Alaska at Valdez has been projected. Studies of such a pipeline are being made, and also on the feasibility of running combined tanker-icebreakers through the Northwest passage.

The oil discoveries in the Arctic are very important, and cannot help but have a large effect upon the extension of surface transportation routes in Alaska.

References

- Alaska Sportsman, November 1967
 Dobrin, Milton B., 1960, Introduction to Geophysical Prospecting, Second Ed.: McGraw-Hill Book Co., New York
 Fisher, R. P., and Fisher, F. S., 1968, Interpreting pan-concentrate analyses of stream sediments in geochemical exploration for gold: U. S. Geological Survey Circ. 592
 Herreid, Gordon, 1968, Tectonics and Ore deposits in Alaska: reprinted in Final Report, Mineral Resources of Northern Alaska, M.I.R.L. Report No. 16, p. 171
 Parasnis, D. C., 1965, Mining Geophysics: Elsevier Publishing Co., New York, 356 p.
 Wilson, J. Tuzo, 1968, A revolution about the Earth: Geotimes, v. 13, p. 10

SOURCES OF INFORMATION AND AID TO PROSPECTORS

Since the writing of the first edition, several new sources of information have become available. The University of Alaska has stepped up its research activities through the establishment of several Institutes and Laboratories. The Mineral Industry Research Laboratory, which has published this book and the Institute of Social Economic and Government Research are two agencies which could help the Alaskan prospector with information.

The Federal Field Committee for Development Planning has commissioned several reports relating to economic development.

Both the U. S. Geological Survey and the Alaska Division of Mines and Geology are now making geochemical surveys, the results of which are made available to the public.

The U. S. Geological Survey now publishes as a four-volume Professional Paper, short summaries of results of work during the past year. These are very useful in keeping abreast of the latest work by the Survey (see e.g. Prof. Paper 600-A, B, C, D).

The Alaska Division of Mines and Geology administers a Prospector's Assistance Program. Under this program a prospector whose plan of work is accepted, may be reimbursed for 75% of certain of his expenses.

It should be noted that the headquarters for the Division of Mines and Geology is now at College, Alaska, not Juneau. The petroleum functions have now been taken over by a new Division of Oil and Gas, headquartered in Anchorage. The Nome office of the Division of Mines and Geology is no longer operating.

BIBLIOGRAPHY

Publications of The United States Geological Survey

GEOLOGIC MAPS

- GQ 366 Mt. Hayes D-3, 1965
- GP 447 Aeromagnetic reconnaissance of the east central Tanana Lowland, Alaska, 1964
- OM 95 Geology of the Iniskin Peninsula, Alaska, Kirschner, Minard, 1949
- I-407 Preliminary map, Iliamna quadrangle, 1964
- I-410 Northern part of McCarthy A-4 quadrangle, 1964
- I-411 Reconnaissance, Baranoff and Kruzof Islands, 1964
- I-415 Extent of glaciations in Alaska, 1965
- I-423 Preliminary geologic map, McCarthy C-4 quadrangle, 1964
- I-437 Regional geology, Kateel River quadrangle, 1966
- I-438 Preliminary geologic map, McCarthy B-5 quadrangle, 1966
- I-444 Preliminary geologic map, McCarthy C-6 quadrangle, 1965
- I-445 Permafrost map of Alaska, 1965
- I-448 Geologic and crustal cross section of U.S. along the 37th parallel, 1965
- I-453 Map of eastern Prince William Sound, Alaska, showing fracture traces inferred from photographs, 1965
- I-455 Geologic map of Fairbanks quadrangle, 1966
- I-459 Regional geologic map, Hughes quadrangle
- I-469 Geologic map of Kwiguk and Black quadrangles, 1966
- I-484 Geologic map of Gulf of Alaska Tertiary Province, 1967
- I-492 Regional geologic map, Candle quadrangle, 1967
- I-507 Multiple glaciation, Yukon-Tanana upland, 1967
- I-523 Geologic map of the Hooper Bay quadrangle, Alaska, Hoare, Condon, 1968
- I-524 Engineering geologic map of the southeastern Copper River basin, 1969
- I-520 Regional geologic map of Selawik and southeastern Baird Mountains quadrangle, 1968

HYDROLOGIC ATLASES

- HA 200 Chemical quality of public water supplies of U. S. (by States), 1964
- HA Flood of August 1967 at Fairbanks Alaska, Childers, Meckel, 1967
- HA 259 Water resources and surficial geology of the Mendenhall Valley, Alaska, Barnwell, Baring, 1968

ALASKA IN GENERAL

- Prof. Paper 400 A Geological research 1960, Synopses of geologic results, 1960
- B Short papers in the geologic sciences, Articles 1-232, 1960 contains articles on the following:
- 16 Geochemical results near Nome, Hummel, Chapman
 - 17 Mineral deposits near Nome, Hummel
 - 18 Five quicksilver deposits in southwestern Alaska, Sainsbury, Mackevett
 - 19 Possible mineral resource potential in southeastern Alaska, Berg
 - 36 Aeromagnetic surveys, possible petroleum provinces, Zietz, Andreassen, Grantz
 - 39 Coal reserves of the United States, 1960, Averitt
 - 48 Soil and plant sampling at the Mahoney Creek lead-zinc deposit, Revillagigedo Island, Shacklette
 - 49 Geochemical exploration in Alaska, Chapman, Shacklette
 - 63 Effects of a roadway on permafrost, Greene, Lachenbruch, Brewer
 - 152 Cenozoic sediments beneath the central Yukon Flats, Williams
 - 153 Cook Inlet, glacial record and Quaternary classification, Karlstrom
 - 154 Surficial deposits of Alaska, Karlstrom
 - 155 Recent sea-level fluctuations, Arctic beach ridges, Moore
 - 156 Stratigraphic section Lisburne group, Pt. Hope, Campbell
 - 157 Marine fauna probably late Pliocene near Kivalina, Hopkins, MacNeil
 - 158 Broad magnetic highs, Alaska and California, Grantz, Zietz
 - 159 Matanuska formation, south-central Alaska, Grantz, Jones
 - 160 Radiocarbon dates, Gubik formation, Coulter, Hussey, O'Sullivan

Prof. Paper 400 B (continued)

- 161 Meta-sedimentary rocks, south-central Brooks Range, Brosgård
- 181 Rate of melting at the bottom of floating ice, Barnes, Hobbie
- 186 Thermal contraction cracks and ice wedging in permafrost, Lachenbruch
- 187 Contraction-crack polygons, Lachenbruch

Prof. Paper 424 A Geological Survey Research, 1961. Synopsis of geologic and hydrologic results, 1961

B Short papers in the geologic and hydrologic sciences, Articles 1-146 contains articles on the following:

- 90 Reconnaissance of the Kandik and Nation Rivers, Brabb
- 101 Pennsylvanian rocks southeastern Alaska, Dutro, Douglass

C Short papers in the geologic and hydrologic sciences, Articles 147-292 contains articles on the following:

- 151 Beryllium in stream sediments, Seward Peninsula, Sainsbury, Helz, Annell, Westley
- 183 The quartz diorite line in northwestern North America, Moore, Grantz, Blake
- 218 Phenoclasts in glaciolacustrine deposits, Copper River Basin, Schmoll
- 220 Sorting of beach sediment, northwestern Alaska, Moore
- 231 Correlation of the Arctic Permian, Dutro

Prof. Paper 424 D Short papers in the geologic and hydrologic sciences, Articles 293-435, 1961 contains articles on the following:

- 353 Analyses, mineral springs in the Copper River Basin, Nichols, Yehle
- 354 Thrust faults, Lisburne Hills, Campbell
- 355 Processes of sedge meadow pool formation, Latouche Island, Shacklette
- 356 Regionally metamorphosed contact-metasedimentary deposits near Nome, Hummel
- 357 Multiple glaciation headwaters of the Delta River, Péwé
- 358 Recession of Portage Glacier, Schmidt
- 374 Early Cretaceous microfossils in south-central Alaska, Berquist
- 383 Gravity low at Minto Flats, Barnes
- 418 November 1960 Project Chariot, cratering experiment, Cape Thompson, Kachadoorian

- 419 Engineering geology, Yukon-Koyukuk lowland, R. Weber, Péwé

Prof. Paper 432 Upper Cretaceous (Campanian and Maestrichtian) ammonites from southern Alaska, D.L. Jones, 1963 (1964)

Prof. Paper 450 A Geological Survey Research 1962, Synopses of geologic, hydrologic, and topographic results, 1962

B Short papers in geology, hydrology, and topography, Articles 1-59, 1962 contains articles on the following:

- 11 Radiocarbon dates, widespread volcanic ash deposit, eastern Alaska, Fernald

C Short papers in geology and hydrology, Articles 60-119, 1962 contains articles on the following:

- 65 Variation in rank of Tertiary coals in the Cook Inlet basin, Barnes
- 94 Gravimetric determinations, ice thickness, Jarvis Glacier, Ostenso, Holmes

D Short papers in geology, hydrology, and topography, Articles 180-239, 1963 contains the following article:

- 203 Quartz diorite line in northwestern North America, Moore, Grantz, Blake

Prof. Paper 475 A Geological Survey Research, 1963, Summary of Investigations, 1963

B Short papers in geology and hydrology, Articles 1-59m 1963 contains articles on the following:

- 16 Potassium-argon and lead-alpha ages for plutonic rocks, Talkeetna Mountains, Grantz, Thomas, Stern, Sheffey
- 27 Aerial reconnaissance of the outer Shumagin Islands, Grantz
- 28 Linear topographic features, southern Baranof Island, Brew, Loney, Pomeroy, Muffer
- 38 Influence of snow cover on frost penetration, Krinsley
- 48 Waterpower investigations of lakes in Alaska, Johnson
- 52 Chemical quality of shallow ground water, northwestern Alaska, Feulner, Shupp

C Short papers in geology and hydrology, Articles 60-121, 1963 contains articles on the following:

- 68 Stratigraphic nomenclature and age, Tuxedni Group, Cook Inlet region, Dettmer
- 79 Possible Pleistocene-Recent boundary in Gulf of Alaska, based on benthonic Foraminifera, Smith
- 91 Glaciolacustrine diamicton deposits in the Copper River Basin, Alaska, Ferrians

- Prof. Paper 475 D Short papers in geology and hydrology, Articles 122-172, 1964 contains articles on the following:
- 148 Rich oil shale from northern Alaska, Tailleir
 - 153 New occurrences of the rugose coral *Rhizophyllum* in North America, Oliver
- Prof. Paper 482 Physiographic divisions of Alaska, Wahrhaftig, 1965
- Prof. Paper 492 Thermal springs of the United States and other countries of the world - A summary, Waring, revised by Blankenship, Bentall, 1965
- Prof. Paper 501 A Geological Survey Research 1964, Chapter A. 1964
- B Geological Survey Research 1964, Chapter B. 1964
 - C Geological Survey Research 1964, Chapter C. 1964 contains articles on the following:
 - Laumontite in Cretaceous sedimentary rocks, western Alaska, Hoare, Condon, Patton
 - Ore controls at Kathleen-Margaret (MacLaren River) copper deposit, MacKevett
- D Geological Survey Research 1964, Chapter D. 1964 contains articles on the following:
- Triassic ostracodes from Alaska and Nevada, Sohn
 - Water from a well drilled through permafrost near Bethel, Feulner, Schupp
- Prof. Paper 525 A Geological Survey Research 1965, Chapter A. 1965 (1966)
- B Geological Survey Research 1965, Chapter B. 1965 contains articles on the following:
 - Low-volatile bituminous coal, Mississippian, Lisburne Peninsula, Tailleir
 - Potassium-argon ages of plutonic rocks, Chicago Island, Lanphere, Loney, Brew
 - Rock glacier, Johnson River area, Alaska Range, Foster, Holmes
 - C Geological Survey Research 1965, Chapter C. 1965 contains articles on the following:
 - Upper Triassic undevitrified volcanic glass, Hound Island, Keku Strait, Brew, Muffler
 - Jurassic mafic igneous complex, Christian quadrangle, Reiser, Lanphere, Brosgé
 - Middle (?) Ordovician, Devonian (?), and Cretaceous (?) rocks, White Mountain area, near McGrath, Sainsbury
 - Glaciation in the Nabesna River area, Fernald
 - Recent history of the upper Tanana River lowland, Alaska, Fernald
 - Birch Creek pingo, Krinsley
 - D Geological Survey Research 1965, Chapter D. 1965 contains articles on the following:
 - Jurassic plutonism, Cook Inlet region, Detterman, Reed, Lanphere
 - Radiocarbon dates, Iliamna Lake, Detterman, Reed, Rubin
 - Oldhamia, a Cambrian trace fossil, in east-central Alaska, Churkin, Brabb
 - Stratigraphy of glacial drift, Anchorage, Trainer, Waller
- Prof. Paper 540 Twin Creek Limestone (Jurassic) in western interior of the United States, Imlay, 1967
- Prof. Paper 541 The Alaska Earthquake, March 27, 1964: Field investigations and reconstruction effort, Hansen, et.al.
- Prof. Paper 543 J Effects of the Alaska earthquake of March 27, 1964 on shore processes and beach morphology, Stanley, 1968
- Prof. Paper 544 C Hydrologic effects of the earthquake of March 27, 1964, outside Alaska, Vorhis, with sections on Hydroseismograms from the Nunn-Bush Shoe Co. well, Wisconsin, Rexin, Vorhis, and Alaska earthquake effects on ground water in Iowa, Coble, 1967
- D Effects of the March 1964 Alaska earthquake on glaciers, Post, 1967
- Prof. Paper 545 C Effects of the earthquake of March 27, 1964 on the Alaska Highway system, Kachadoorian, 1968
- Prof. Paper 550 A Geological Survey Research 1966, Chapter A. 1966
- B Geological Survey Research 1966, Chapter B. 1966 contains articles on the following:
 - Tertiary fossils from the Orca Group, Prince William Sound region, Plafker, MacNeil
 - Granulite and peridotite inclusions, Prindle Volcano, Yukon-Tanana Upland, Foster, Forbes, Ragan
 - Hydrothermal alteration near Kennecott copper mines, Wrangell Mountains, MacKevett, Radtke
 - C Geological Survey Research 1966, Chapter C. 1966 contains articles on the following:
 - Upper Mesozoic rocks in southwestern Wrangell Mountains, Grantz, Jones, Lanphere
 - Pyrophyllite in the Kekiktuk Conglomerate, Brooks Range, Reed, Hemley

- Prof. Paper 550 D Geological Survey Research 1966, Chapter D. 1966 contains articles on the following:
- Cretaceous stratigraphy of the Kamishak Hills, Alaska Peninsula, Jones, Detterman
 - Plutonic belt in west-central Alaska, Miller, Patton, Lanphere
 - Ages of Tertiary plutons, Prince William Sound Region, Alaska, Lanphere
- Prof. Paper 553 Cenozoic pectinids of Alaska, Iceland, and other northern regions, MacNeill, 1967
- Prof. Paper 559 A Stratigraphy of the Cambrian and Ordovician rocks of east-central Alaska, Brabb, 1967
- Prof. Paper 567 Dictionary of Alaska Place Names, Orth, 1967
- Prof. Paper 575 A Geological Survey Research, 1967
- B Geological Survey Research, 1967, Chapter B. 1967 contains articles on the following:
- Veins at Black Mountain, western Seward Peninsula, Sainsbury, Hamilton
 - Evidence for Devonian age of Nation River Formation, east-central Alaska, Scott, Doherty
 - Development of a ground-water supply at Cape Lisburne by modification of the thermal regime of permafrost, Feulner, Williams
- C Geological Survey Research 1967, Chapter C. 1967 contains articles on the following:
- Use of an infiltration gallery to obtain fresh water at Ocean Cape, Feulner, Heyward, Angelo
- Prof. Paper 600 A Geological Survey Research 1968 (1968)
- C Geological Survey Research 1968
- D Geological Survey Research 1968 (1968)
- Bull. 1155 Contributions to economic geology of Alaska, 1963 contains the following papers:
1. The Funter Bay nickel-copper deposit, Admiralty Island, Alaska, Barker
 2. Exploration for antimony deposits at Stampede mine, Kantishna district, Alaska, Barker
 3. Coal deposits along the Yukon River between Ruby and Anvik, Alaska, Chapman
 4. Examination of uranium prospects, 1956, Freeman
 5. Summary of reconnaissance for uranium in Alaska, 1955, Matzko, Freeman
 6. Investigations for perlite in the Alaska Range, Pfaffner, Wahrhaftig, Eckhart, Moxham
 7. Copper prospect site in upper Chitina Valley, Alaska, Seitz
 8. Tungsten prospect on Kodiak Island, Alaska, Seitz
 9. Radiometric investigations along the Taylor Highway and part of the Tanana River, Alaska, Nelson, Matzko
 10. Radiometric traverse along the Yukon River from Fort Yukon to Ruby, Alaska, 1949, White, Stevens, Matzko
- Bull. 1198 C Bryophytes associated with mineral deposits and solutions in Alaska, Shacklette, 1965
- Bull. 1200 Lexicon of geologic names of the United States for 1936-1960, Keroher and others, 3 vol. 1966
- Bull. 1223 Nickel deposits of North America, Cornwall, 1966
- Bull. 1242 B Coal resources of Alaska, F.F. Barnes, 1967
- Bull. 1246 Metalliferous lode deposits of Alaska, Berg, Cobb, 1967
- W.S. 1740 Compilation of records of surface waters of Alaska, Oct. 1950-Sept. 1960, 1964
- W.S. 1760 Ground-water levels in the United States, 1956-1960, Northwestern States, 1963
- W.S. 1800 Role of ground water in national water situation, McGuinness, 1963
- W.S. 1809 E Galleries and their use for development of shallow ground-water supplies, with special reference to Alaska, Feulner, 1964
- W.S. 1953 Quality of surface waters of Alaska, 1961-1963, 1965
- Circ. 493 Magnitude and frequency of floods in Alaska south of the Yukon River, Berwick, Childers, Kuentzel, 1964
- Circ. 516 Index of surface-water records to Dec. 31, 1963, Alaska, Eisenhuth, 1965
- Circ. 533 Regional trends in water-well drilling in the United States, Meyer, Wyrick, 1966
- Circ. 560 U. S. Geological Survey heavy metals program progress report, 1966 and 1967, 1968
- Circ. 585 Index of surface-water records to Sept. 30, 1967, Alaska, Eisenhuth, 1968

ALEUTIAN ISLANDS

- Prof. Paper 454 B, C Pillowed lavas, I: Intrusive layered lava pods and pillowed lavas, Unalaska Island, Alaska, and Pillowed lavas, II: A review of selected recent literature, Snyder, Fraser, 1953
- Bull. 1260 K Summary report on the geology and mineral resources of the Bering Sea, Bogoslof, Simeonof, Semidi, Tuxedni, St. Lazaria, Hazy Islands, and Forrester Island National Wildlife Refuges, Alaska, Cobb, Wanek, Grantz, Carter, 1968

BERING SEA

- Bull. 1260 K Summary report on the geology and mineral resources of the Bering Sea, Bogoslof, Simeonof, Semidi, Tuxedni, St. Lazaria, Hazy Islands, and Forrester Island National Wildlife Refuges, Alaska, Cobb, Wanek, Grantz, Carter, 1968

COOK INLET - SUSITNA

- Prof. Paper 398 A Tertiary stratigraphy and paleobotany of the Cook Inlet region, Alaska, Wolfe, Hopkins, Leopold, 1966
B Tertiary plants from the Cook Inlet region, Alaska, Wolfe, 1966
- Prof. Paper 418 A Late Bajocian ammonites from the Cook Inlet region, Alaska, Imlay, 1962
B Middle Bajocian ammonites from the Cook Inlet region, Alaska, Imlay, 1964
- Prof. Paper 443 Quaternary geology of the Kenai Lowland and glacial history of the Cook Inlet region, Alaska, Karlstrom, 1964
- Prof. Paper 512 Geology of the Iniskin-Tuxedni region, Alaska, Detterman, Hartsock, 1966 (1967)
- Prof. Paper 542 A Effects of the earthquake of March 27, 1964 at Anchorage, Alaska, Hansen, 1965
- Prof. Paper 543 F Ground breakage and effects in the Cook Inlet area, Alaska, resulting from the March 27, 1964 earthquake, Foster, Karlstrom, 1967
- Prof. Paper 544 B Effects of the March 1964 Alaska earthquake on the hydrology of the Anchorage area, Alaska, Waller, 1966
- Prof. Paper 545 A Effect of the earthquake of March 27, 1964 on the Eklutna Hydroelectric Project, Anchorage, Alaska, Logan, U. S. Bureau of Reclamation, with a section on Television examination of earthquake damage to underground communication and electrical systems in Anchorage, Burton, 1967
B Effects of the earthquake of March 27, 1964 on air and water transport, communications and utilities systems in south-central Alaska, Eckel, 1967
- Prof. Paper 547 Cretaceous Ammonites from the lower part of the Matanuska Formation, southern Alaska, Jones, with a Stratigraphic summary, 1967
- Bull. 1181 I Stratigraphic reconnaissance of the Matanuska Formation in the Matanuska Valley, Alaska, Grantz, 1964
- Bull. 1202 C Geology and coal resources of the Beluga-Yentna region, Alaska, Barnes, 1966
- Bull. 1254 E Schists of the central Alaska Range, Wahrhaftig, 1968
- W.S. 1773 Geology and ground-water resources of the Anchorage area, Alaska, Cederstrom, Trainer, Waller, 1964
- W.S. 1779 D Hydrology and the effects of increased ground-water pumping in the Anchorage area, Alaska, Waller, 1964
- Circ. 491 Alaska's Good Friday earthquake, March 27, 1964, a preliminary geologic evaluation, Grantz, Plafker, Kachadoorian, 1964 (see Prof. Paper 542 A.)
- Circ. 564 Occurrences of gold and other metals in the Upper Chulitna valley, Alaska, Hawley, Clark

COPPER RIVER

- Prof. Paper 542 B Effects of the earthquake of March 27, 1964, at Whittier, Alaska, Kachadoorian, 1965 (1966)
C Effects of the earthquake of March 27, 1964, at Valdez, Alaska, Coulter, Migliaccio, 1966
- Prof. Paper 543 B Geomorphic effects of the earthquake of March 27, 1964, in the Martin-Bering Rivers area, Alaska, Tuthill, Laird, 1966
C Gravity survey and regional geology of the Prince William Sound epicentral region, Alaska, Case, Barnes, Plafker, Robbins, 1966
E Effects of the earthquake of March 27, 1964, in the Copper River Basin area, Alaska, Ferrians, 1966

- Prof. Paper 544 A Effects of the March 1964 Alaska earthquake on the hydrology of south-central Alaska, Waller, 1966
- Prof. Paper 545 B Effects of the earthquake of March 27, 1964 on air and water transport, communications and utilities systems in south-central Alaska, Eckel, 1967
- Prof. Paper 573 A Recent Foraminifera from the Gulf of Alaska and southeastern Alaska, Todd, Low, 1967
- Bull. 1180 A Cretaceous stratigraphy of the McCarthy A-4 quadrangle, southern Alaska, Jones, Berg, 1964
- Circ. 593 Distribution of gold and some base metals in the Slana area, eastern Alaska Range, Alaska, Richter, Matson, 1968
- Circ. 604 Distribution of gold, copper and some other metals in the McCarthy B-4 and B-5 quadrangles, Alaska, MacKevett, Smith, 1968

KENAI PENINSULA

- Prof. Paper 443 Quaternary geology of the Kenai Lowland and glacial history of the Cook Inlet region, Alaska, Karlstrom, 1964
- Prof. Paper 542 D Effects of the earthquake of March 27, 1964 in the Homer area, Alaska, Waller, with a section on Beach changes on Homer Spit, Stanley, 1966
- E Effects of the earthquake of March 27, 1964 at Seward, Alaska, Lemke, 1967
- F Effects of the earthquake of March 27, 1964 on the communities of Kodiak and nearby islands, Kachadoorian, Pfalker, 1967
- Prof. Paper 543 A Slide-induced waves, seiching, and ground fracturing caused by the earthquake of March 27, 1964 at Kenai Lake, Alaska, McCulloch, 1966
- Prof. Paper 544 A Effects of the March 1964 Alaska earthquake on the hydrology of South-central Alaska, Waller, 1966
- Prof. Paper 545 B Effects of the earthquake of March 27, 1964 on air and water transport, communications, and utilities systems in south-central Alaska, Eckel, 1967
- HA 187 Water resources and surficial geology of the Homer area, south-central Alaska, Waller, Feulner, Morris, 1968

KODIAK ISLAND

- Prof. Paper 543 D Geologic effects of the March 1964 earthquake and associated seismic sea waves on Kodiak and nearby islands, Alaska, Pfalker, Kachadoorian, 1966

KUSKOKWIM

- Bull. 1187 Quicksilver deposits of southwestern Alaska, Sainsbury, MacKevett, 1965
- Circ. 569 Geochemical anomalies and metalliferous deposits between Windy Fork and Post River, southern Alaska Range, Reed, Elliott, 1968

NORTHERN ALASKA

- Prof. Paper 395 Areal geology in the vicinity of the Chariot site, Lisburne Peninsula, northwestern Alaska, Campbell, 1967
- Prof. Paper 414 C Some observations on the hydrochemistry and sedimentation of the Chamberlin Glacier area, Alaska, Rainwater, Guy, 1961
- Prof. Paper 539 Potential effects of Project Chariot on local water supplies, northwestern Alaska, Piper, 1966
- Bull. 1201 B Quaternary geology of the Mount Chamberlin area, Brooks Range, Alaska, Holmes, Lewis, 1965
- Bull. 1242 E Coal resources of the Cape Lisburne-Colville River region, Alaska, Barnes, 1967

NORTHWESTERN ALASKA

- Bull. 1181 K Surficial geology of the central Kobuk River valley, northwestern Alaska, Fernald, 1964

SEWARD PENINSULA

- Bull. 1242 F Geochemical cycle of selected trace elements in the tin-tungsten-beryllium district, western Seward Peninsula, Alaska - A reconnaissance study, Sainsbury, Hamilton, Huffman, 1968
- Circ. 614 Metalliferous deposits near Granite Mountain, eastern Seward Peninsula, Alaska, Miller, Elliot, 1969

SOUTHEASTERN ALASKA

- Prof. Paper 573 A Recent foraminifera from the Gulf of Alaska and southeastern Alaska, Todd, Low, 1967
- Bull. 1178 Stratigraphy and petrography of the Pybus-Gambier area, Admiralty Island, Alaska, Loney, 1964 (1965)
- Bull. 1181 R Reconnaissance geology of Admiralty Island, Alaska, Latham, Pomeroy, Berg, Loney, 1965
- Bull. 1211 A Geologic reconnaissance of the West Creek damsite near Skagway, Alaska, Callahan, Wayland, 1965
- Bull. 1211 B Geologic reconnaissance of possible powersites at Tyee, Eagle, and Spur Mountain Lakes, southeastern Alaska, Callahan, Wanek, 1969
- Bull. 1241 C Stratigraphy of the Keku Islets and neighboring parts of Kuiu and Kupreanof Islands, southeastern Alaska, Muffler, 1967

YUKON RIVER

- Prof. Paper 1241 H Pingos in Central Alaska, Holmes, Hopkins, Foster, 1968
- Bull. 1181 H Geologic reconnaissance along the Alaska Highway, Delta River to Tok Junction, Alaska, Holmes, 1965
- Bull. 1198 F Phytocology of a greenstone habitat at Eagle, Alaska, Shacklette, 1966
- Bull. 1241 B Geology of the Mount Fairplay area, Alaska, Foster, 1967
- Bull. 1249 Geology of the Johnson River area, Alaska, Holmes, Foster, 1968
- Bull. 1254 E Schists of the central Alaska Range, Wahrhaftig, 1968
- Bull. 1274 D The coal-bearing group in the Nenana coal field, Alaska, Wahrhaftig, Wolfe, Leopold, Lanphere, 1969
- Circ. 570 Suggested areas for prospecting in the central Koyukuk River region, Alaska, Miller, Ferrans, 1968
- Circ. 590 Potential for lode deposits in the Livengood gold placer district, east central Alaska, Foster, 1968
- Circ. 611 Asbestos occurrence in the Eagle C-4 quadrangle, Alaska, Foster, 1969

Publications of the United States Bureau of Mines
(Note inclusion of Open File Reports - OFR)

ALASKA IN GENERAL

- R. I. 6300 Analyses of tippie and delivered samples of coal, collected during fiscal year 1962, Aresco, Janus, Walker, 1963
- R. I. 6461 Analyses of tippie and delivered samples of coal, collected during fiscal year 1963, Aresco, Janus, Walker, 1964
- R. I. 6497 Electric smelting of titaniferous iron ores from Alaska, Montana, and Wyoming, Holmes, Banning, 1964
- R. I. 6792 Analyses of tippie and delivered samples of coal, collected during fiscal year 1965, Aresco, Janus, Walker, 1966
- R. I. 6904 Analyses of tippie and delivered samples of coal, collected during fiscal year 1966, Aresco, Janus, 1967
- R. I. 7059 Sulfur content of crude oils of the free world, McKinney, Shelton, 1967
- R. I. 7104 Analyses of tippie and delivered samples of coal collected during fiscal year 1967, Aresco, Janus, 1968
- I. C. 8209 Survey of burning coal-mine refuse banks, Stahl, 1964
- I. C. 8221 Analyses of natural gases of the United States, 1961, Miller, Norrell, 1964
- I. C. 8252 Mercury potential of the United States, Staff, 1965
- I. C. 8268 Zircon, a review with emphasis on West Coast resources and markets, Kauffman, Holt, 1965
- I. C. 8290 Titanium resources of the United States, Peterson, 1966
- I. C. 8301 Forms of sulfur in U. S. Coals, Walker, Hartner, 1966
- I. C. 8302 Analyses of natural gases of the United States, Moore, Miller, Shrewsbury, 1966
- I. C. 8356 Analyses of natural gases, 1966, Moore, Shrewsbury, 1967
- I. C. 8395 Analyses of natural gases, 1967, Moore, Shrewsbury, 1968
- I. C. 8396 Prospecting and exploring for radioactive minerals: supplement to facts concerning Uranium exploration and production, Staff, 1968
- I. C. 8452 Heavy crude oil, resources, reserve, and potential production in the United States, Petroleum Staff, 1967
- Bull. 623 State compensatory provisions for occupational diseases, Morgis, Beauregard, Shoub, 1967

Bull. 643 Yields and analyses of tars and light oils from carbonization of U. S. Coals, Walters, Ortuglio, Glaenger, 1967

OFR 11-67 Resumé of information on Alaska bituminous coals with particular emphasis on coking characteristics, Warfield, 1967

BRISTOL BAY

R. I. 6214 Reconnaissance of beach sands, Bristol Bay, Alaska, Berryhill, 1963

COOK INLET - SUSITNA

R. I. 6238 Investigation of a subbituminous coal deposit suitable for opencut mining, Beluga River coalfield, Alaska, Warfield, 1968

OFR 43 Investigations of subbituminous coal deposits in the Beluga River coalfield, Alaska, Warfield, 1961

OFR 3-66 Investigation of the Bailey Copper prospect, Willow Creek mining district, South central Alaska, Maloney, 1966

OFR 7-66 Sampling and coking studies of coal from Castle Mountain mine, Matanuska coalfield, Alaska, Warfield, Landers, Boley, 1966

OFR 9-67 Sampling of gold-copper deposit, Golden Zone mine, South central Alaska, Mulligan, Warfield, Wells, 1967

KODIAK ISLAND

OFR 42 Examination of coal deposits, Sitkinak Island, Alaska, Warfield, 1963

KUSKOKWIM

R. I. 6892 Investigations of the White Mountain mercury deposit, Kuskokwim River basin, Alaska, Maloney, 1967

OFR 4-66 Investigation of the Nixon Fork area, Kuskokwim River basin, Alaska, Maloney, 1966

OFR 5-66 Investigation of the Purkeypile prospects, Kuskokwim River basin, Alaska, Maloney, Thomas, 1966

OFR 16-68 Soil sampling at the Egnaty Creek mercury prospect, Kuskokwim River basin, Alaska, Maloney, 1968

NORTHERN ALASKA

R. I. 6767 Sampling and coking studies of coal from the Kukpowruk River area, Arctic North-western Alaska, Warfield, Landers, Boley, 1966

SEWARD PENINSULA

R. I. 6587 Tin-Iode investigations, Potato Mountain area, Seward Peninsula, Alaska, Mulligan, 1965

R. I. 6737 Tin-Iode investigations, Cape Mountain area, Seward Peninsula, Alaska, Mulligan, Gnagy, 1966

T.P. 4 Marine heavy metal project offshore Nome, Alaska, Jenkins, Lense, 1968

OFR 1 Reconnaissance sampling of beach and river mouth deposits, Norton Bay and Kotzebue Sound, Seward Peninsula, Alaska, Berryhill, 1962

OFR 1-65 Beryllium investigations at the Lost River mine, Seward Peninsula, Alaska, Berryhill, Mulligan, Gnagy, 1965

OFR 2-65 Bureau of Mines diamond drill sampling data, Lost River tin mine, Seward Peninsula, Alaska, Heide, Mulligan, 1965

OFR 6-65 Examination of the Hannum lead prospect Fairhaven district, Seward Peninsula, Alaska, Mulligan, 1965

OFR 7-64 Diamond-drill sampling data, fluorite-beryllium deposits, Lost River Valley, Seward Peninsula, Alaska, Mulligan, Gnagy, 1964

OFR 8-65 Examination of the Sinuk and Iron deposits, Seward Peninsula, Alaska, Mulligan, Hess, 1965

SOUTHEASTERN ALASKA

OFR 12-67 Sampling the Moth Bay zinc-copper deposit, Revillagigedo Island, South-eastern Alaska, Warfield, Wells, 1967

YUKON RIVER

- OFR 39 Galena-bearing gossans, Beaver Creek, Ruby District, Yukon Region, west-central Alaska, Thomas, 1964
 OFR 9-65 Preliminary investigation of limestone, quartzite, and dolomite resources near the proposed Rampart dam in central Alaska, Thomas, 1965
 OFR 10-65 Reconnaissance of the Avnet manganese prospect, Tanana quadrangle, Central Alaska, Thomas, 1965

Publications of the Alaska Division of Mines and Geology

INFORMATION CIRCULARS

- Proper Claim Staking in Alaska, Revised 1968
 Mineral Rights of Aliens in the State, I. C. No. 2, Revised 1968
 Hand Placer Mining Methods, Revised 1968
 Uranium Prospecting in Alaska, Revised 1968
 General Alaskan Mineral Information, Revised 1968
 Alaskan Prospecting Information, Revised 1968
 Compulsory Assessment Work Affidavits, Discontinued
 Mineral Industry Consultants Available for Work in Alaska, Revised 1968
 Dealers in Alaskan Rocks and Minerals, Revised 1968
 Skin Diving for Gold in Alaska, Revised 1968
 List of Division of Mines and Geology publications, Revised 1968
 Services of the Division of Mines and Minerals, Revised 1968
 Dangers in Old Mine Openings, 1962
 Mining Laws Applicable in Alaska, Revised 1966
 The Mineral Industry of the Kenai-Cook Inlet-Susitna Regions, Rose, 1962
 Tectonics and Ore Deposits in Alaska, 1964, reprinted in M.I.R.L. Rept. No. 16, 1968
 A possible Guide to Metal Deposits of Alaska, 1964, reprinted in M.I.R.L. Rept. No. 16, 1968

Map: Better-Known Mineral Deposits, Possible Petroleum Provinces, and Existing Roads

GEOLOGIC REPORTS (Price \$1)

- Preliminary Report on Geologic Mapping in the Coast Range Mineral Belt, Herreid, 1962.
 Available in reprint form
 Bedrock Geology of the Rainbow Mountain Area, Alaska Range, Alaska, M.S. thesis, University of Alaska in cooperation with the Division of Mines and Minerals, Hanson, 1963
 Geology of the Portage Creek-Susitna River Area, Richter, 1963 (2 large sheets)
 Geology and Mineral Deposits of the Denali-Maclaren River Area, Alaska, Kaufman, 1964
 Geology of the Niblack Anchorage Area, Southeastern Alaska, Herreid, 1964
 Geology of the Dry Pass Area, Southeastern Alaska, Herreid, Kaufman, 1964
 Geology of the Paint River Area Iliamna Quadrangle, Alaska, Richter, Herreid, 1965
 A Geologic and Geochemical Traverse Along the Nellie Juan River, Kenai Peninsula, Alaska, Herreid, 1965 (no charge)
 Geology of the Bluff Area, Salomon Quadrangle, Seward Peninsula, Alaska, Herreid, 1965
 Geology of the Omiak-Otter Creek Area, Bendeleben Quadrangle, Seward Peninsula, Alaska, Herreid, 1965
 Geology of the Bear Creek Area, Seward Peninsula, Candle Quadrangle, Alaska, Herreid, 1965
 Geology and Geochemical Investigations Near Paxson, Northern Copper River Basin, Alaska, Rose, Saunders, 1965
 Geology and Mineral Deposits of the Rainy Creek Area, Mt. Hayes Quadrangle, Alaska, Rose
 Geology and Mineralization of the Midas Mine and Sulphide Gulch Areas, Near Valdez, Alaska, Rose, 1965
 Geology and Mineral Deposits of Central Knight Island, Prince William Sound, Alaska, Richter, 1965
 Geology and Geochemistry of the Hollis and Twelvemile Creek Areas, Prince of Wales Island, Southeastern Alaska, Herreid, Rose, 1966
 Geology of Chromite-Bearing Ultramafic Rocks Near Eklutna, Anchorage Quadrangle, Alaska, Rose, 1966
 Geology of part of the Amphitheatre Mountains, Mt. Hayes Quadrangle, Alaska, Rose, 1966

- Geological and Geochemical Investigations in the Eureka Creek and Rainy Creek Areas, Mt. Hayes Quadrangle, Alaska, Rose, 1966
- Geology of the Slana District, Southcentral Alaska, Richter, 1966
- Geology and Geochemistry of the Nixon Fork Area, Medfra Quadrangle, Alaska, Herreid, 1966
- The Geology and Geochemistry of the Inmachuk River Map Area, Seward Peninsula, Alaska, Herreid, 1966
- Preliminary Geology and Geochemistry of the Sinuk River Area, Seward Peninsula, Alaska, Herreid, 1966
- Geological and Geochemical Investigations in the Metal Creek Area, Chugach Mountains, Alaska, Richter, 1967
- Geological and Geochemical Investigations Southwest of Farewell, Alaska, Herreid, 1968
- Geology and Mineral Deposits of the Dolomi Area, Prince of Wales Island, Alaska, Herreid, 1967
- Geology of the Upper Chistochina River Area, Mt. Hayes Quadrangle, Alaska, Rose, 1967
- Progress Report on the Geology and Geochemistry of the Sinuk Area, Seward Peninsula, Alaska, Herreid, 1968
- Geology of the Upper Slana-Mentasta Pass Area, Southcentral Alaska, Richter, 1967
- Geology and Stream Sediment Geochemistry of Anton Larsen Bay and Vicinity, Kodiak Island, Alaska, Rose, Richter, 1967
- Geology of an Area on the Upper Talkeetna River, Talkeetna Mountains Quadrangle, Alaska, Rose, 1967

GEOCHEMICAL REPORTS (Price \$1)

- Geochemical Investigations of Selected Areas in Southeastern Alaska, Herbert, Race, 1965; out of print, included in Geochemical Report #6
- Geochemical Investigation of the Slana District, Southcentral Alaska, 1963 and 1964, Richter, 1965
- A Geochemical Investigation in the Richardson Area, Big Delta Quadrangle, Alaska, Saunders, 1965
- Geochemical Investigations of Selected Areas in Southcentral Alaska, Jasper, 1965
- A Geochemical Investigation Between Chatanika and Circle Hot Springs, Alaska, Burand, 1965
- Geochemical Investigations of Selected Areas in Southeastern Alaska, 1964 and 1965, Herbert, Race, 1965
- Geochemical Investigations Along Highway and Secondary Roads in Southcentral Alaska, 1965, Jasper, 1966
- Geochemical and Geological Investigations of Admiralty Island, Alaska, Rose, 1967
- A Geochemical Investigation Along the Taylor Highway, East-Central Alaska, Saunders, 1966
- A Geochemical Investigation of the Nenana Highway Area, Central Alaska, Burand, 1966
- A Geochemical Investigation of Stream Sediments in the Elliott Highway Area, Alaska, Burand, 1966
- A Geochemical Investigation of Minook Creek, Rampart District, Alaska, Burand, Saunders, 1966
- Geochemical Investigations of Selected Areas in the Yukon-Tanana Region of Alaska, 1965 and 1966, Burand, 1968
- Geochemical Investigations Willow Creek Southerly to Kenai Lake Region, Southcentral Alaska, Jasper, 1967
- Geochemical Investigations Along the Valdez to Chitina Highway in Southcentral Alaska, 1966, Jasper, 1967
- A Geochemical Investigation of a Portion of the Fortymile District, Alaska, Smith, 1968
- A Geochemical Investigation of the Wood River-Tikchik Lakes Area, Southwestern Alaska, Eakins, 1968
- The Great Alaska Earthquake, March 27, 1964, 1964
- Mine Safety Regulations, 1963, from the Alaska Administrative Code

SPECIAL REPORTS (Price \$1)

- Mineral Occurrences in the Yukon-Tanana Region, Alaska, Saunders, 1967
- History of Mines and Prospects, Ketchikan District, Prior to 1952, Bufvers, 1967

Unpublished Theses and Papers of the University of Alaska

- Structures in the Upper Snow Layers of the Southern Dome of the Greenland Ice Sheet, Davis, 1962
- Configuration of the Surface Velocity Profile of Gulkana Glacier, Central Alaska Range, Alaska, Moores, 1962
- Foliation and Other Structures of Gulkana Glacier, Central Alaska Range, Alaska, Rutter, 1962
- Flow and Ablation of Gulkana Glacier, Central Alaska Range, Alaska, Sellman, 1962
- 1961 Meteorology and Mass Balance of Gulkana Glacier, Central Alaska Range, Alaska, Mayo, 1963
- Recent Glacial History of Gulkana and College Glaciers, Central Alaska Range, Alaska, Reger, 1964
- Surficial Geology and Geomorphology of the Harding Lake Area, Big Delta Quadrangle, Alaska, Blackwell, 1965
- Bedrock Geology of the Gulkana Glacier Area, Alaska Range, Bond, 1965
- Coal Petrography as Related to Section, Preparation and Coking of Certain Alaskan Coals, Hankinson, 1965
- The Feasibility of Utilization of Certain Alaskan Bloating Shales for Lightweight Aggregate, Loskamp, 1965
- Geology and Ore Deposits of Kantishna and Vicinity, Kantishna District, Alaska, Morrison, 1965
- Bedrock Geology Between Rainy Creek and Denali Fault, Eastern Alaska Range, Alaska, Stout, 1965
- Expansion Properties of Selected Elliott Highway Shales, Heiner, 1966
- Trace Element Copper Distribution and Areal Geology in a Portion of the Clearwater Mountains, Alaska, Glavinovich, 1967
- Geochemistry and Petrology of the Mt. Trident Andesites, Katmai National Monument, Alaska, Ray, 1967
- Visible region absorption spectra for selected metamorphic and igneous amphiboles, Robinson, 1967
- Nature and Distribution of Sediments in the Norris Glacier Outwash Area, Upper Taku Inlet, Southeastern Alaska, Statt, 1967
- An Economic Analysis of a Hydrometallurgical Copper Facility for Alaska, Stoney, 1967
- Snow stratigraphic studies of the summit caldera of Mt. Wrangell, Alaska, Wharton, 1967
- Geology and Petrology of the Fairbanks Basalts, Alaska, G. A. Furst, 1968
- The Reconnaissance Petrology of Andesites from the Mt. Wrangell Caldera, Alaska, M. J. Furst, 1968
- A Paleoenvironmental Analysis of the Three Late Pleistocene Coleopterous Assemblages from Fairbanks, Alaska, Matthews, 1968
- Biostratigraphy and Lower Permian Fusulinidae of the Upper Delta River Area, East Central Alaska Range, Petocz, 1968
- Petrology of the Ahtell Creek Pluton, Eastern Alaska Range, Phillips, 1968
- Ablation of Ice Island Arles II, 1961, Schraeder, 1968
- A Geological and Geochemical Investigation of Mineralization on Hill 3560, Fortymile District, Alaska, Smith, 1968
- The Beneficiation of a Copper Bearing Talus Material, Kiehn, 1969
- Gravity Survey of Katmai National Monument, Kienle, 1969
- The Petrofabrics of Auefs in a Turbulent Alaskan Stream, Kreitner, 1969
- Miscellaneous Publications of College of Earth Sciences and Mineral Industry (Formerly School of Mines)
- Determinative mineralogy for the Alaskan prospector, Wilkerson, 1938, revised as Mining Ext. Bull. No. 1, Anthony, 1961
- Map, Recording Districts and withdrawn areas in Alaska, Wolff, 1952
- Map, Recording Districts and withdrawn areas in Alaska, revised, Anthony, 1963
- Map, Recording districts and system of rectangular surveys, 1963
- Introductory prospecting and mining, editions of 1958, 1961, 1966 (CESMI Bull. 4), Anthony
- Handbook for the Alaskan Prospector, Wolff, 1964

Publications of the Mineral Industry Research Laboratory, University of Alaska

- MIRL No. 1 Annual report of research progress, 1965
- MIRL No. 2 The Market Potential for Alaskan Clay Products, Beasley
- MIRL No. 3 Petrographic evaluation of Coking Potential of Selected Alaskan Coals and Blends, Hankinson, 1965
- Alaska cement markets and opportunities for regional production (published as Inst. of Bus., Econ. and Gov't Research Mon. No. 4, 1965)
- MIRL No. 4 Market for Insulation in Alaska and Feasibility of Regional Manufacture, Haring, Beasley, 1965
- MIRL No. 5 Annual report of research progress, 1965 (1966)
- MIRL No. 6 Investigation of Lightweight Aggregates in Alaska, Heiner, Loskamp, 1966
- MIRL No. 7 Annual report of research progress, 1966 (1967)
- MIRL No. 8 Natural Resource Base of the Fairbanks-North Star Borough, Wolff, Haring, 1967 (with Inst. of Soc., Econ. and Gov't Research)
- MIRL No. 9 Fortran IV Trend-Surface program for the IBM Model 40 Computer, Heiner, Geller, 1967
- MIRL No. 10 Trace Element Copper Distribution and Areal Geology in a Portion of the Clearwater Mountains, Alaska, Glavinovich, 1967
- MIRL No. 11 Applications of Trend Surface Analysis and Geologic Model Building to Mineralized Districts in Alaska, Heiner, Wolff, 1967
- MIRL No. 12 Geochemical-Geophysical Investigations, Fairbanks District, Alaska, Heiner, Beistline, et. al.
- MIRL No. 13 Preliminary Report, Mineral Resources of Northern Alaska, Wolff, Heiner, Lu, 1968 (for NORTH Commission)
- MIRL No. 14-A Annual report of research progress, 1967 (1968)
- MIRL No. 15 Distribution of Certain Minor Elements in Alaskan Coals, Rao, 1968
- MIRL No. 16 Final Report, Mineral Resources of Northern Alaska, Heiner, Wolff, 1968
- MIRL No. 17 Development of a Lightweight Low Cost Self Potential Unit, Zonge, 1968
- MIRL No. 18 Known and Potential Ore Reserves, Seward Peninsula, Alaska, Lu, Heiner, Harris, 1968
- MIRL No. 19 Handbook of Geophysical Prospecting Methods for the Alaskan Prospector, Heiner, Wulf, 1968
- MIRL No. 20 Heavy Minerals in Alaskan Beach Sand Deposits, Cook, 1969
- MIRL No. 21 Washability Characteristics of Low-Volatile Bituminous Coal from Bering River Field, Alaska, Rao, 1969

Handbook for the Alaskan Prospector (revised), Wolff, 1969

Pertinent Publications of the Federal Field Committee
for Development Planning in Alaska

BASIC RESOURCE INFORMATION

- Alaska Recreation and Government Policies, Saroff, 1967
- Alaska Study, Public Land Law Review Commission, due 1969
- Alaska, the Land and the People, Fitzgerald, presented to 1967 Symposium on Circumpolar Health-Related Problems, College, Alaska, 1967
- Economic Development in Alaska, Federal Field Committee, 1966
- Environmental Influences Study, Hickok, due 1969
- General Plan for the National Assessment of Water and Related Land Resources, Water Resources Council, 1967
- Regional Development Planning: The Alaskan Experience, D. N. Jones, 1968
- The Strategy of Regional Development Planning, Tussing, 1968

NATIVE AFFAIRS

- Alaska Natives and Federal Hire, Arnold, Wunnicke, 1967
- Alaska Natives and the Land, Federal Field Committee, 1968
- Alaska Native Claims: Major Elements of a Proposed Settlement, Federal Field Committee staff, 1969
- Comparative Analysis of Land Claim Settlement Proposals, Federal Field Committee staff, 1968; Addenda, 1969
- Northwest Alaska Regional Resources Development, University of Alaska, due 1969
- Westward Alaska and the Native Condition, Abrahamson, 1968
- Villages in Alaska and Other Places Having a Native Population of 25 or More, Federal Field Committee with Bureau of Indian Affairs and U. S. Public Health Service, 1967

ECONOMIC DEVELOPMENT

- Alaska Power Survey, Federal Power Commission, due 1969
 Alaska Trade Study, Federal Maritime Commission, 1967
 Railways in Resource Development, Fitzgerald, 1969
 Remarks to the Transportation Symposium of the 19th Alaska Science Conference, Fitzgerald, 1968
 Federal Regulation of Transportation in Alaska, Chertkov, 1967
 Transportation and Economic Development in Alaska, Transportation Task Force of Federal Field Committee, 1968

REGIONAL INFLATION AND GOVERNMENT PROGRAMS

- Studies of Alaska Regional Inflation, University of Alaska and Federal Field Committee, 1968 (part), balance due 1969

SPECIFIC INDUSTRY AND RESOURCE DEVELOPMENT

- Alaska-Japan Economic Relations, University of Alaska, 1968
 Alaska-Northwest Canada Economic Relations, Herbert, Rogers, Jones, 1967, 1968
 Disposal of Alaska Communication System, Jones, 1967
 A Program for Increasing the Contribution of Tourism to the Alaskan Economy, Cresap, McCormick and Paget, 3 vols., 1968
 Mineral Policy, the Public Lands and Economic Development: The case of Alaska, University of Alaska, 1969
 A Subregional Economic Analysis of Alaska, Jones, Tussing, et. al., 1968

ECONOMIC AND FINANCIAL INFORMATION

- An Aggregate Income Model of a Semi-Autonomous Alaskan Economy, Tuck, 1967
 Fairbanks Flood Disaster and Alaska's Economy, Tuck, Jones, 1967
 Selected Economic Indicators, Tuck, 1966, 1967
 Summary of Alaskan Industries, Bye, 1967
 Taxation and Economic Development in Alaska, Jones, 1966

Miscellaneous Publications

GOVERNMENT

- Transport requirements for the growth of northwest North America, 3 vol., Battelle Mem. Inst., 1961, 87th Congress, 1st Session, House Doc. No. 176
 Mineral and water resources of Alaska, U. S. G. S., Alaska Dept. Nat. Res., at request of Gruening, 1964, U. S. Senate Committee Print
 Alaska natural resources and the Rampart project, Interior Dept., 1967

PRIVATE

- Alaska Mining Law, Roden, 1955
 Alaska mining law manual, Herbert, 1967
 Dictionary of Alaska place names, U. S. Geological Survey Prof. Paper 567, Orth, 1967
 Dictionary of mining, mineral and related terms, U. S. Bureau of Mines, Thrush, editor, 1968
 Examination and valuation of mineral properties, Parks, 1957
 Tectonic history and mineral deposits of the western Cordillera, C. I. M. Geology Division, Spec. vol. No. 8

INDEX

- Aa lava, 135
- Abrasion, 103
- Abrasion platform, 131
- Abrasion placers, 158
- Abrasives, 43
- Absorption effect, radiometric prospecting, 377
- Acadia, 90
- Acadian disturbance, 89
- Accessory minerals in igneous rocks, 63
- Accordant junction, 108
- Acicular crystal habit, 5
- Acid, acidic, igneous rocks, 63
- Acid taste of minerals, 9
- Acquiring mineral claims, 344, 419
- Actinolite, 9, 23, 24, 41
- Activator, radioactivity, 278
- Adamantine luster, 7
- Adit, 189, 191
 - line of, 351
- Adjustment to structure, 108
- Adularia, 147
- Adventive cone, 135
- Aerial photographs, 295, 297
- Aftonian Interglacial Age, 98
- Agate, 45, 289
- Age of earth, 82
- Age of fishes, 90
- Age of glaciations, 98
- Ages, geologic time, 83
- Agglomerate, 67, 70
- Aggradation of permafrost, 112
- Aggrading stream, 103
- Aid for prospector, sources of, 371
- Airborne magnetic survey, 268
- Airplane drill, 237
- Alabaster, 30, 45, 71
- Alaska, geographic, geologic features, 364
 - geography, 358
 - present status, mining, prospecting, 172
 - provinces, 137, 142
 - recording districts, 359
 - State Division of Mines and Minerals, 372, 407, 423
 - State publications, 405, 432
- Alaska in general, USBM literature, 400, 430
 - USGS literature, 381, 424
- Alaska judicial districts, 359
- Alaska mining history, 174, 177
- Alaska mining law, 343-357, 418-429
- Alaska Peninsula, USGS literature, 384
- Alaska Range, 137
- Alaskan terms, glossary of, 377
- Albite, 29
- Aleutian Islands, USBM literature, 400
 - USGS literature, 385, 428
- Alexandrite, 44, 288
- Algonian Revolution, 87
- Algonkian Era, 84
- Alkaline taste of minerals, 9
- Alloy steel, 309
- Alluvial material; alluvium, 104
- Alluvial plains, 110
- Alpha particles, use in prospecting, 275
- Alpine glaciers, 118
- Alpine topography, 119
- Aluminum, 42
 - test for, 17
- Altiplanation terraces, 116
- Amalgam, silver, sodium, 316
 - treatment of, 315, 316
- Amalgamating plates, 316
- Amazon stone, 29
- Amblygonite, 44
- Amethyst, 36, 44, 288, 289
- Ammonia, dynamite, gelatine, 301
- Amorphous minerals, 3, 61
- Amphibole, 147
 - to distinguish from pyroxene, 64
- Amphibolite, 66
- Amygdaloidal crystal habit, 6
- Amygdules, 150, 288
- Analcime, 41
- Analysis of present mining status in Alaska, 172
- Analysis of samples, 283
- Ancient abrasion platform placers, 158
- Ancient igneous and metamorphic shields, 137
- Ancient placers, 157, 159
- Andalusite, 38, 45, 163
- Andesine, 29
- Anglesite, 23, 42, 59
- Angular unconformity, 77
- Anhydrite, 23, 54, 59, 71
- Annabergite, 34
- Annealing of steel, 312
- Annual labor, 346, 419
- Annular drainage, 108
- Anomalies, 266
- Anorthite, 26
- Anorthosite, 66, 166
- Antecedent drainage, 110
- Anthracite, 73
- Anticline, 77
 - breached, 110
- Anticlinorium, 78
- Antigorite, 37
- Antimony, 42, 148, 161, 164
 - test for, 17
- Antler Orogeny, 408
- Antlerite, 42
- Anvil, block and, 308
- Apatite, 7, 23, 44, 56, 57, 59
- Apex of vein, 348
- Aphanite, 65
- Aplite, 65, 66

- Appalachia, 90
 Appalachian field, 91
 Appalachian trough, 88
 Apparatus needed for chemical identification, 10
 Appliances used in prospecting, how to build, 317
 Application of geophysical methods in prospecting, 279
 Aquamarine, 24, 44
 Archean Era, 84
 Archeozoic Era, 82, 84
 Arctic slope, 137, 367
 clothing for, 341
 Area affected in metamorphism, 73
 Area, factors affecting choice for prospecting, 180
 Arenaceous sedimentary rocks, 69
 Arête, 121
 Argentite, 23, 43, 48, 147
 Argillaceous sedimentary rocks, 69
 Argillaceous smell of minerals, 8
 Arid cycle in fold or block mountains, 128
 Arid lands, processes and surface forms of, 127
 Arkose, 70
 Arrangement and scope of bibliography, 379
 Arsenic, 23, 42, 49, 50, 161
 test for, 18
 Arsenopyrite, 23, 42, 50, 147
 Artesian water, 132
 Asbestos, 24, 37, 45, 55, 57, 58, 162, 166
 group, 24
- Babbitting of drill cable, 241
 Babiche, 326
 Back, 180
 mining of, 189
 Back of drift, 191
 Backsight reading, 292
 Back slope of fault block, 134
 Backboard, 210
 Background count of locality, 275
 Background information for prospector, 171
 Badlands topography, 96, 127
 Bahada, 128
 Banded crystal habit, 6
 Bannock, 338
 Bar, baymouth, offshore, 131
 river, 107
 sinker, for drilling, 239
 turning, for thawing, 219
 Barchans, 128
 Barite, 24, 45, 55, 56, 57, 58, 155
 Barium, test for, 18
 Barrack point, 219
 Barren zone, 164
 Barrier beach, 131
 Barrier reef, 136
 Basal conglomerate, 69
 Basal till, 122
 Basalt, 66, 289
 Base level, 103
 Base map, 189
 Base metals, 139, 167
 Baseline, 291
 Basement, 84
 Basic igneous rocks, 63, 288
 Basin, nested saucer, 137
- Ash, volcanic, 135
 Assay foot, inch, map, 195
 Assay limits, 186
 Assay, of mineral, 10, 195
 Assay offices, 195, 423
 Assay walls, 186
 Assembling drill tools and accessories, 239
 Assessment work, 346, 419
 Associated igneous rock, control by type of, 166
 Association claims, 350, 419
 Association of minerals, 10
 Astringent taste of minerals, 9
 Asymmetrical folds, 78
 Atlantic type coast, 129
 Atoll, 136
 Atom, 3
 Atomic absorption analyses, 415
 Atomic Energy Commission, functions of, 372
 Aufeis, 116, 211
 Augers, 300
 Augite, 24, 49, 53, 54, 55, 56, 64, 66
 Augitite, 66
 Aureole, 146
 Austentite, 312
 Auxiliary techniques in prospecting, 290
 Axial plane or surface, of folds, 77
 Axis, crystal, 5
 Axis of fold, 78
 Azimuths, 290
 Azurite, 24, 55
- B**
- Basin, structural, 78
 Basin of deposition, 163
 Basket sled, 323
 Batholith, 61, 165
 Bauxite, 24, 42, 54, 56, 57, 58, 59, 69, 155
 Bayhead beach, 131
 Baymouth bar, 131
 Beach, 131
 wave cut, 124
 Beach placer, 158, 159
 Bead tests, 11, 14, 15
 Beaded drainage, 114
 Bearing set, 226
 Bearings, mapping, 290
 Bearpaw snowshoes, 326
 Bears, protection against, 332, 336
 Becker hammer drill, 411
 Bedding, control of by faults, 163
 Bedding faults, 80
 Bedrock, 103
 Beds, in rock, 83
 Beheaded stream, 107
 Beltian Series, 86
 Bench, stream, 107
 wave cut, 130
 Bench claims, 350
 Bench cut round, holes, 190, 191
 Bench placer, 157
 Bending metal, 310
 Beryl, 24, 44, 54, 56, 58, 60, 288, 289
 Beryllium meter, 278
 Beta particles, use of in prospecting, 275
 Bibliography, arrangement and scope of, 378
 Billet, 308, 309
 Biotite, 24, 49, 53, 55, 56

- Birch Creek Schist, 83, 87
 - Biscuit board topography, 119
 - Bismuth, 25, 42, 50, 51, 161, 165
 - test for, 18
 - Bismuthinite, 25
 - Bits, 204, 239, 300, 311
 - Bitter taste of minerals, 9
 - Bituminous odor of minerals, 9
 - Black Band iron ore, 152
 - Black Mica, 24
 - Black sands, 31, 33, 157, 314
 - Blacksmithing, 307, 308
 - equipment, materials, tools, 307, 308
 - Bladed crystal habit, 5
 - Blanket, for drill hole, 247
 - Blanket deposits, leasing of, 356
 - Blaster's Handbook, 306
 - Blasting, drilling rock for, 299
 - Blasting agents, 303
 - Blasting caps, 302, 304
 - Blind hole, 203
 - Blind valley, 133
 - Block fault, low angle, 80
 - Block mountains, 110
 - arid cycle in, 128
 - Block of ground, 213
 - Block of ore, 195
 - calculating value of, 197
 - Block riffles, 320
 - Blockholing, 306
 - Blowouts, 128
 - Blowpipe tests, 10, 17
 - Bog iron ore, 71
 - Boilers, 217
 - accessories, operation, 218, 219, 220
 - methods, techniques in using, 220
 - Bolson plains, 127
 - Bombs, 63, 135
 - Books on mining and prospecting, 406, 434
 - Booming to trace veins, 188
 - Booming with a dam, 209
 - Bootlegs, 304
 - Boots, use and types of, 340
 - Borax, 44
 - Bore holes, prospecting with, 198
 - Bornite, 25, 42, 51, 147
 - Bornite, Alaska, copper, 410
 - Boron, test for, 18
 - Bottom cut holes, 190
 - Bottom deposits, glacial lake, 124
 - Bottomset beds, 76
 - Botryoidal crystal habit, 6
 - Boulder clay, 122
 - Boulder trains, 123
 - Boulders, blasting of, 304, 306
 - perched, 123
 - Box, drilling, 339
 - Boxwork, 160
 - Braided streams, 107, 123
 - Brazilian emerald, 44
 - Breached anticlines, 110
 - Breached cone, 135
 - Breached streams, 110
 - Break-to holes, 190
 - Breakage, primary, 304
 - secondary, 304, 306
 - Breaker waves, 129
 - Breccia, 67, 69, 70, 80, 135, 150
 - Bridges, natural, 133
 - Bridges, timbering of, 192
 - Brief history of Alaskan mining, 174
 - Bristol Bay, USBM literature, 400, 430
 - USGS literature, 385
 - Brittleness of minerals, 8
 - Broad geographic and geologic features of Alaska, 364
 - Bromine, test for, 18
 - Bronzite, 9, 288
 - Brooks Range, 136, 137, 367
 - Brownstone, 70
 - Brunton compass, use in prospecting, 185
 - use in mapping, 290
 - Buckets, self dumping, 215
 - Bucyrus drill, 237
 - Building prospecting appliances, 317
 - Bull quartz, 194
 - Bull ring, 241
 - Bunting, use of in mapping, 291
 - Bureau of Land Management, functions, 373
 - publications, 404
 - Buried placers, 157, 159
 - Burrowing animals, diggings noted to trace veins, 188
 - Butting sluice boxes, 318
 - Buzz saw, 324
 - Bytownite, 29
- C
- Cadmium, 42, 161
 - test for, 18
 - Cache, camp, 333
 - dynamite, 303
 - Caisson, sinking, 229
 - evaluating hole, 231
 - Caisson log, 233
 - Calamine, 38
 - Calaverite, 40, 42
 - Calc-sinter, 71
 - Calcareous caliche, 71
 - Calcareous organic, sedimentary rocks, 71
 - Calcic marble, 74
 - Calcite, 7, 25, 45, 53, 54, 55
 - Calcium, test for, 18
 - Calculating drill holes, 249, 258, 260, 262
 - Calculating frozen holes, 253
 - Calculating thawed holes, 250
 - Calculating results of sampling, 194
 - Calculating value of ore, 196
 - Caldera, 135
 - Caliche, 71
 - Calving, glacial, 119
 - Cambrian period, 82, 87, 88
 - Camp, 180, 321, 340
 - clothing, 340
 - communications, 330
 - equipment needed, 321, 323-330
 - food, 321, 335, 338, 417
 - shelter, 321, 331
 - techniques, transportation, 321
 - Canadian shield, 86, 142

- Cap rock falls, 107
- Capacities, volumes, weights, 374
- Capillary crystal habit, 5
- Caps, dynamite, 302, 303
- Caps, timbering, 190, 192
- Capture, stream, 107
- Carbon dating, 84, 99
- Carbon steel, 309
- Carbonaceous organic sedimentary rocks, 72
- Carbonates, 71, 153
- Carboniferous rocks, 90
- Carbonization of minerals, 17
- Carnallite, 43
- Carnelian, 44
- Carnotite, 25, 43, 56
- Carriers, self dumping, 215
- Cartridge, dynamite, 301
- Cascadian Revolution, 96, 98
- Cased holes in thawed ground, 243
- Cash bonus, coal leasing, 355
- Casing factor, use of, 250
- Casing the diamond drill hole, 201, 243
- Casing ring, 241
- Casing sizes, 205
 - for churn drill, 376
- Casing slips, spear, wedges, 241
- Cassiterite, 25, 43, 49, 50, 51, 53, 54, 55, 57, 58, 147, 155, 288, 289
- Cast iron, 309
- Casting off part of claim, 348
- Cat head, 242
- Catcher, core, 201
- Catchment basin, 105
- Cave, sea, 130
- Cave-in lakes, 114
- Caverns, 133
- Cavity filling, 143, 147
 - solutions, 150
- Celestite, 25, 44, 54, 55, 59
- Cement, 45
- Cemented sediments, 69
- Cementing minerals in sedimentary rocks, 69
- Cenozoic Era, 83, 95
- Center of crystal, 5
- Central lowland and plateau region, Alaska, 365
- Central uplift, 408
- Cerargyrite, 25, 58, 59
- Cerussite, 26
- Cervantite, 26, 56, 67
- Chabazite, 41
- Chain wrench bar, 239
- Chalcedony, 26, 58, 60
- Chalcocite, 9, 26, 28, 42, 48, 50
- Chalcopyrite, 26, 42, 51, 147, 288
- Chalk, 25, 71
- Chambered veins, 148
- Channel, stream, 106
- Channel sample of vein, 194
- Charcoal, reactions on, 10, 12
- Charges, 306
 - preparation of, 304
- Chatter marks, 119
- Chemical controls of mineralization, 164
- Chemical industry, use of non-metals, 43
- Chemical origin of sedimentary rocks, 69
- Chemical tests for minerals, 10
- Chemical weathering, 103
- Chert, 71
- Chief transportation and communication routes in Alaska, 368
- Chile saltpeter, 44
- Chip sample of vein, 194
- Chlorine, test for, 18
- Chlorite, 26, 55
- Choppers, 340
- Chopping bit, 201
- Chromite, 26, 42, 49, 53, 166, 288
- Chromium, 42
 - test for, 19
- Chrysoberyl, 44, 288
- Chrysocolla, 26, 55, 56
- Chrysotile, 37, 45
- Churn drill tools and casing sizes, 376
- Churn drilling, 199, 237
- Churning or spudding, 237
- Cinder cones, 62, 135, 137
- Cinnabar, 27, 43, 52, 55
- Circles in patterned ground, 116
- Cirque glaciers, 119
- Cirques, 119
 - topographic features of, 121
- Claims, acquiring, 344, 346, 347, 419
 - leasing requirements, 354, 421
 - lode, 347, 348, 419, 420
 - patenting, 353, 420
 - placer, 350, 419, 420
- Clamshell digger, 411
- Clans of igneous rocks, 65
- Classification of coasts, 129
- Classification of geomorphic units, 136
- Classification of igneous rocks, 63, 67
- Classification of mineral deposits, 143
- Clastic wedge, 408
- Clay, 45, 69, 70, 152, 153, 155
- Clay ironstone, 152
- Claystone, 69
- Cleanup, paddle, procedure, 315
- Cleaning the hole after thawing down, 223
- Cleavage, 80
 - in minerals, 8
 - in rocks, 81
- Clinton Iron Ore, 89
- Closed folds, 78
- Closed tube, 15, 16
- Closure, structural, 78
- Clothing in camp life, 321, 323, 340
- Coal, 72, 91, 153
 - leasing, 354, 355, 421
- Coal bearing group, 97
- Coasts, features of, 130, 131
 - types of, 129
- Coastal plain, 129, 131, 136
- Cobalt, 42, 148, 155, 161
 - test for, 19
- Cobaltite, 27, 42, 50
- Cockade ore, 148
- Cockscomb structure, 33
- Coeur d'Alene, Idaho silver-lead province, 142
- Col, 121
- Cold cutter, 308
- Cold lands, processes and surface forms, 111
- Cold weather drilling problems, 249
- Collapse breccia, 70, 150
- College of Earth Sciences and Mineral Industry, mining short course, 373
- literature, 434

- Colloform crystal habit, 6
- Colloid, 70
- Colloidal sedimentary structures, 70
- Colluvial placers, 158
- Color changes in minerals, 7
 - in closed tube, 16
- Color in tempering tools, 313
- Color of mineral, 7
- Color of oxidation products, 161
- Colorado group, 94
- Colorations, flame, 11, 13
- Colorimetry, geochemical prospecting, 283
- Colors, heat, 313
- Columbite, 27, 48, 49, 288
- Columbium, 27
 - test for, 19
- Column, geologic, 295
- Column mountings for drill, 300
- Columnar crystal habit, 5
- Columnar jointing, 80
- Comb structure, 147
- Colville, Alaska, geosyncline, 409
- Commercial materials, metals, 42
- Commercial non-metals, 43
- Commodity, factors affecting choice in
 - prospecting, 180
- Common opal, 34
- Common sedimentary rocks, 71
- Communication in camp, 330
- Communication routes of Alaska, 368
- Compensator, electromagnetic, 413
- Competence of rocks, 77
- Complementary shears, 186
- Complex mountains, 134
- Complex ore, 139
- Components of folds, 77
- Composite cone, 135
- Composite veins, 148
- Composition of igneous rocks, 63
- Composition of intrusive, invaded, rocks, 146
- Compound, 3
 - oxidized, 161
- Compound volcanoes, 63
- Comstock lode, 148
- Concentrate, 157, 314
- Concentration, magmatic, 140
- Concentric crystal habit, 6
- Concentric fold, 78
- Concoidal fracture of minerals, 8
- Concordant igneous bodies, 62
- Concretions, 70
- Conditioning reagent, geochemical
 - prospecting, 285
- Conditions justifying prospecting, 184
- Cone, volcanic, 62, 135, 137
- Conglomerate, 69, 288
- Consequent lake, 111
- Consequent stream, 105, 110
- Consolidated sediments, 69
- Constitution of earth, 1
- Constructive forces, 133
- Contact metamorphism, 73, 140
- Contact metasomatic deposits, 140, 146
- Continental drift, 2
- Continental glaciers, 118, 137
 - erosional features of, 122
- Continental platform stage, 408
- Continental shelf, 2
- Continental type rocks, 2
- Continuous zone of permafrost, 112
- Contour, 292
- Contour interval, map, 102, 292
- Contour of penetrating edge of bit, 311
- Contraposed coast, 132
- Control by igneous rock, 163, 164, 166
- Convection current, 407
- Cook Inlet, USBM literature, 401, 430
 - USGS literature, 386, 428
- Cooling taste of minerals, 9
- Copper, 27, 42, 51, 52, 148, 153, 161, 165, 166
 - Kobuk, 176, 410
 - provinces, 142
 - test for, 19
- Copper River-White River, 142
- Copper River, USBM literature, 401
 - USGS literature, 388, 428
- Copper-zinc, 148
- Coral, 72, 136
- Coral islands, 137
- Cordillera, 407
- Cordilleran glacier complex, 99
- Cordilleran trough, 88
- Core, before and after pumping, 242
 - Diamond drill, 199
 - drilling of the, 203, 245
- Core barrel, catcher, lifter, 201
- Core box, 204
- Core of batholith, 165
- Core of double tube drill, 203
- Core of earth, 1
- Correlation in proving age of rocks, 84
- Corundum, 7, 27, 43, 44, 53, 55, 58, 59, 60, 167, 288
- Cosmic rays, radiometric prospecting, 275, 277
- Country rock, 139
- Course, mapping, 294
- Covellite, 25, 27, 42, 52
- Cover effect, radiometric prospecting, 277
- Crater, 62, 135
- Crater Lake, Oregon, 135
- Creek, crosscutting, 211
- Creek claims, 350
- Creek factor, use in calculations, 253
- Creep, mass wasting, 104
- Crenulate shoreline, 131
- Crest, wave, 129
- Cretaceous Period, 93, 94, 95, 142
- Crevasse, 119
- Cribbing, 226, 234
- Critical temperature of metal, 311, 312
- Cross-bedding of sediments, 76
- Cross sections, 293
- Crosscut, 191
- Crosscutting, 184, 211, 224
- Crown sheave pulley, 237
- Crust of earth, 1
- Crustification, 148
- Cryolite, 28, 58, 59
- Cryptocrystalline, 3
- Cryptozoic Eon, 82, 84
- Crystal, 3, 5, 6
 - optical, 44
 - rock, 36, 44
- Crystalline minerals, 61

Crystallization of igneous rock, 64
 Crystallographic axes, 5
 Crystallographic systems, 6
 Cupola, 165
 Cuprite, 28, 54
 Cuspate foreland, 132
 Cut holes, 190
 Cutbanks, 105
 Cutter, blacksmithing, 308

Dacite, 66
 Dakota sandstone, 94
 Dating, radioactive, 84, 89
 Dating rocks by fossils, 83
 Dead line of batholith, 165
 Decimated sample, 195
 Decomposition of rocks, 103
 Decrepitation of minerals, 10, 17
 Definitions, Alaskan, 377
 of mining terms, 180
 Deflagrating explosives, 301
 Deflation, wind, 127
 Degradation of permafrost, 112
 Degrading stream, 103
 Dekken, 134
 Delay electric blasting caps, 304
 Delta, 76
 glacial, 124
 Delta plains, 137
 Dendrites, 70
 Dendritic crystal habit, 5
 Dendritic drainage, 105
 Density of high explosives, 302
 Deoxidation spheres, 70
 Deposition, basins of, 163
 Depositional features of glaciers, 122
 Deposits, common sedimentary, 71
 epigenetic, igneous, mineral, ore, secondary,
 139
 evaporite, residual, 141
 glacio-fluvial, 123
 hydrothermal, 140, 147, 201
 hydrothermal replacement, 151
 lake bottom, 124
 magmatic, 144
 metasomatic replacement, 150
 terrestrial, 84
 varved, 111
 wind, 70
 Depth control of mineral deposition, 151
 Descriptions of minerals, 23
 Desert areas, plains, 137
 Desert pavement, 127
 Destruction of explosives, 303
 Determinative mineralogy, 46
 tables, 47
 Determining tenor of ground in shaft, 226
 Determining distribution of pay streak, 213
 Detonating explosives, 301, 302
 Detrital, 89
 Development, 180, 189, 192
 Devonian Period, 89, 90
 Diabase, 66, 166
 Diagonal approach of waves, 129
 Diamond, 7, 43, 44, 166, 288

Cutting edge of bit, 311
 Cycle, fluvial, 103-105
 frost, 111
 tectonic, 407, 408
 Cycle of erosion, Karst, 133
 Cycle of marine erosion, 131
 Cycle of rock formation, 7
 Cycle of sedimentation, 152
 Cymophane, 288

D

Diamond core drill, drilling, 199, 201
 Diamond drill hole, casing, 201, 263
 Diamond method, calculating drill holes, 258,
 262
 Diastrophism, 2, 102
 Diatomite, 34
 Diatomaceous earth, 58, 72
 Difficulties in drilling, 203, 248, 249
 Digging tools, 237
 Dikes, 61
 Dilated veins, 148
 Dilution of ore by waste, 198
 Dimension stone, 301
 Dinosaurs, 92, 95
 Diopside, 288
 Diorite, 65
 Diorite-andesite clan, 66
 Dip of structure, 77
 Dip slip fault, 79
 Dip needle survey, 268
 Disconformity, 77
 Discontinuous zone of permafrost, 112
 Discordant igneous bodies, 62
 Discordant junction, 108, 119
 Discovery, 344
 lode, notice, stake, 347, 420
 Disintegration, 103
 Disordered structures, 136, 137
 Dispersion through soils, 282
 Disseminated deposits, 144
 Disseminated ore body, 150
 Disseminated replacements, 151
 Distributive provinces, 286
 Disturbances, 83
 Ditch, waste, 208
 Dithizone, geochemical sampling, 283
 Diurnal variation of earth magnetism, 268
 Divergent crystal habit, 5
 Divide, 105
 Divisions of USGS, 371
 Doghouse boiler, 217, 325
 Dogs, use of in prospecting, 323-326
 food required, 338, 339
 picks for, 328
 Dolerite, 65, 66, 166
 Doline, 133
 Dolomite, 28, 45, 53, 71, 288
 Dome, of boiler, 217
 structural, 78
 Dome uplift, 137
 Do's and don'ts for blasters, 307
 Double jacking, 299
 Double tube core barrel, 203
 Drag, 80
 Drag fold, 78
 Drag ore, 186

- Drain, prospecting, 182
 - Drainage, beaded, 114
 - dendritic, 105
 - non-adjusted, 110
 - Drainage patterns, 108
 - in mountains, 110
 - Draw cut round, 191
 - Drawing of metal, 310, 312
 - Drift, glacial, 122
 - in wave action, 129
 - stratified, washed, 123
 - Drift, prospecting, 186, 191
 - timbering, 192
 - Drifters, 299
 - Drill accessories, assembling, 239
 - Drill core, 203, 245
 - Drill equipment, dimensions of, 205
 - Drill favored for crosscutting, 211
 - Drill head, 201
 - Drill holes, casing sizes, 205, 376
 - evaluating ground from, 249, 257, 260, 262
 - in frozen ground, 254
 - in thawed ground, 252
 - profile, 297
 - Drill log, 205
 - Drill mountings, 300
 - Drill rod, 201
 - sizes, 205
 - Drill tools, 239, 376
 - Drills, 199, 201, 237, 238, 299, 300, 411
 - Drilling, 242
 - core, 203
 - dry, wet, 300
 - hand, 299
 - water needed for, 205
 - Drilling axioms, 243
 - Drilling difficulties, 203, 204, 248, 249
 - Drilling in drifts, 191
 - Drilling placer deposits, 236
 - Drilling records, samples, 249
 - Drilling rock for blasting, 299
 - Drilling shafts, 189
 - Dripstone, 133
 - Drive clamp, 241
 - Drive guide, 201
 - Drive shoes, 241
 - Drivehead, 201, 241
 - Drivepipe, extra heavy, 241
 - Drivepipes to trace veins, 188
 - Drowned atoll, 136
 - Drowned out hole, 228
 - Drowned valleys, 129, 131
 - Drumlins, 123
 - Druse, 70
 - Drusy crystal habit, 5
 - Dry drilling, 300
 - Dry frost, 215
 - Dry hanging valleys, 133
 - Dry permafrost, 112
 - Dry walls, 208
 - Dry valley, 133
 - Duck's nest, blacksmithing, 308
 - Ductility of minerals, 8
 - Dull luster of minerals, 7
 - Dumortierite, 45, 163
 - Dump box, 199, 249
 - Dunes, 127, 128
 - Dunite, 66
 - Dust, volcanic, 135
 - Dynamic metamorphism, 73
 - Dynamite, 301-304
 - Dyne, 268
- E
- Embayed coast, 129
 - Emerald, 24, 44, 288
 - Emergent coast, 129, 131
 - Emery, 27, 163
 - Empire hand drill, 238
 - Enargite, 28, 42, 48
 - End moraine, 122
 - End plates, timbering, 226
 - En Echelon faults, 80
 - En Echelon veins, 148
 - Englacial material, 122
 - Eocene Epoch, 96
 - Eolian sediments, 84
 - Epeirogeny, 2, 96
 - Epidote, 28, 53, 56, 58
 - Epigenetic deposits, 139, 145
 - examples, 143
 - Epithermal process of deposits, 147
 - Epochs, metallogenetic, 141
 - Epochs of time, 83
 - Equal standing, 1
 - Equigranular texture of rocks, 65
 - Equilibrium, radioactivity, 275, 277
 - stream, 105
 - Equipment needed, for blacksmithing, 307
 - for drilling placer deposits, 283
 - for sampling, 283
 - for sinking shafts in frozen ground, 215
 - Equipment needed in camp, 321
- Early epigenetic deposits, 139
 - Early magmatic deposits, 144
 - Early primary deposits, metallogenetic, 143
 - Early Tertiary Epoch, 142
 - Earth, constitution, 1
 - Earth movements, 3
 - Earthquake rifts, 111
 - Earthquake waves, 79
 - Earths and sands, 153
 - Earthy luster of minerals, 7
 - Eclogite, 166
 - Economic geology, 1
 - Economic minerals, 3
 - index suite of, 288
 - Effect of glaciation on prospecting, 124
 - Effervescence of minerals, 9
 - Elasticity of minerals, 8
 - Elbow of capture, 107
 - Electric blasting cap, 302, 304
 - Electric squib, 301
 - Electrical methods, prospecting, 271, 413
 - Electromagnetic method, prospecting, 274, 413
 - Electroscope, use in prospecting, 276
 - Element, 3
 - Elements, tests for, 17
 - Elements of mining law, 343, 418-421
 - Elements of symmetry, 5
 - Elevated shore lines, 132
 - Elevation, mapping, 102

- Equipotential lines, 272
- Equipotential surfaces, 273
- Equivalent time-rock units, 82
- Erosion cycle, 102
 - karst, 133
 - marine, 129
 - under arid conditions, 127
- Erosional features of continental glaciers, 122
- Erratic boulder, 122
 - rafted, 124
- Escarpment, 79
- Eskers, 124
- Essential minerals in igneous rocks, 63
- Eugeosyncline, 408
- Evaluating caisson holes, 231, 232, 234
- Evaluating ground from drill holes, 257
- Evaluation, methods, 258, 259, 262, 263, 264
- Evaporation, 154
 - examples of, 143
- Evaporite deposits, 71, 141, 154
- Even fracture of minerals, 8
- Events in formation of mineral deposits, 139
- Evolution, 83
- Examples of mapping by triangulation
 - methods, 293
- Exploitation, 180, 192
- Exploration, 180, 184
 - summary of methods, 186
- Explosives, firing, handling, methods of
 - using, properties, storage, transportation,
 - types, use, 301-307
 - lighters for, 307
- Extralateral rights, 348, 419
- Extrusive rocks, 61, 62

F

- Face of anvil, 308
- Face of drift, 191
- Factors affecting choice of area and
 - commodity sought, 180
- Factors affecting results of scintillometer
 - survey, 277
- Factors considered in drill hole calculations,
 - 250, 253
- Fairbanks drill, 237
- False bedrock, 156, 163
- False gossan, 160
- False set, timbering, 192
- Fans, alluvial, 127
 - outwash, 123
- Fault block mountains, 134, 137
- Fault components, 79, 80
- Fault gouge, 79, 148
- Fault line scarp, 79
- Fault plane, 79
- Fault scarp, 134
- Fault structures, 134
- Faults, 78-80
- Feather edge of bit, 311
- Features of coasts of emergence, 131
- Features of coasts of submergence, 130
- Features of stratified drift, 123
- Features of till, 122
- Federal Field Committee publications, 435
- Feel of minerals, 8
- Feeders, 156
- Feldspar, 7, 45, 55, 58, 59
 - criteria for distinguishing from pyroxene,
 - 64
 - group, 28
- Felsenmeer, 115
- Felsic minerals, 63
- Felsite, 66
- Femag igneous rocks, minerals, 63
- Femic minerals, 63
- Fenster, 134
- Ferberite, 29, 41
- Ferrite, 312
- Ferro-magnesian igneous rocks, minerals, 63
- Ferruginous chemical sedimentary rocks, 71
- Fertilizers, use of non-metals, 44
- Fetid odor of minerals, 9
- Fibrous crystal habit, 6
- Fibrous serpentine, 37
- Filiform crystal habit, 5
- Filter pressing, 140
- Financing prospecting, 171
- Fingering out of veins, 148
- Fjords, 121
- Firing of charges, 306
- First Judicial District, 359
- First order relief features, 102
- First tier claims, 350
- Fishing tools, 242
- Fissure, 135
- Fissure deposits, lode, 151
- Fissure flows, 63
- Fissure veins, 148
- Fitchering bits, 300
- Flagging, use in mapping, 291
- Flagstone, 70
- Flame, blowpipe, 10
 - colorations, 11, 13
- Flatter, blacksmithing, 308
- Flats, 124
 - in Alaska, 408
 - in rocks, 149
- Flexible minerals, 8
- Flint, 71
- Float, tracing, 186
- Flood plain, 106, 137
- Floor of drift, 191
- Flouring of mercury, 316
- Flow cleavage, 81
- Flow layers, lines, of magma, 76
- Flowstone, 133
- Flume, flumehose, 210
- Fluorescence of minerals, 7, 278
- Fluorine, test for, 19
- Fluorite, 7, 29, 44, 45, 54, 56, 58, 59, 288
- Fluvial cycle, 103-111
- Fluviatile deposits, 84
- Fluviatile sediments, 69, 84
- Fluxes, use of non-metals, 44
- Fold mountains, 137
 - arid cycle in, 128
 - Drainage in, 110
- Folded structures, folding, 77
- Folded and faulted structures, 137
- Folds, 77, 78

- Foliated crystal habit, 6
 - Foliated metamorphic rocks, 73, 74
 - Following the ore, 189
 - Food, camp, 321, 335, 338, 339, 417
 - Fools' gold, 35
 - Footwall, fault, 79
 - Footwear, camp, 340
 - Forced waves, 129
 - Foreland, 131, 132
 - Forepole, timbering, 192
 - Foreset beds, 76
 - Foresight reading, mapping, 292
 - Forge, 308
 - Forging operations, 310
 - Formation of mineral deposits, events in, 139
 - Formations, rock, 83
 - Forms, mining, 357, 422
 - Fossils, 76, 83
 - Fourth Judicial District, 360
 - Fox Hills Sandstone, 94
 - Fracture, structural, 78
 - Fracture cleavage, 81
 - Fracture of minerals, 8
 - Franklinite, 29, 49
 - Free use, coal, license, 355
 - Free waves, 129
 - Freeze holes, 337
 - Freezing down holes, 228
 - Freezing resistance, high explosives, 302
 - Freibergite, 40
 - Freighting with dogs, 304
 - Fretted upland, 119
 - Frequency domain in I. P., 414
 - Fringing reef, 136
 - Frost, 112, 215
 - Frost cycle, 111
 - Frost heaving, 104, 114
 - Frost mound, 116
 - Fract wedge polygon, 112
 - Frozen ground, drilling difficulties, 248
 - methods and techniques in, 220
 - open holes in, 247
 - sinking shafts in, 215
 - Frozen holes, calculating values, 253, 255, 256
 - Fuller, blacksmithing, 308
 - Fumeroles, 135
 - Fumes of high explosives, 302
 - Fusibility of minerals, 9
- G
- Gabbro, 65, 166, 288
 - Gabbro-basalt clan, 66
 - Gad, 215
 - Gal, 268
 - Galena, 29, 42, 46, 48, 50, 147, 288
 - Gallons water needed, diamond drilling, 205
 - Gamma rays, use in prospecting, 275
 - Gangue, 139
 - Garlic odor of minerals, 8
 - Garnet, 9, 43, 44, 147, 163, 166, 288, 289
 - group, 30
 - Garnierite, 43
 - Gas, mineralogy tests, 17
 - Gas and oil leases, 355, 421
 - Gauge, pressure, for boilers, 218
 - Gauss, 268
 - Geanticline, 78
 - Geiger counter, 276
 - Gelatine dynamite, 301
 - Gems, 24, 27, 36, 39, 42, 44
 - semi-precious, 45
 - Geochemical prospecting, analysis of samples, 281, 285
 - sampling soil and water, 281, 285, 415
 - to trace veins, 188
 - Geodes, 70, 289
 - Geographical, geologic subdivisions, 360
 - broad features of, 364
 - Geography of Alaska, 358
 - Geologic column, 295
 - Geologic map, reading, 295
 - Geologic mapping, surface, 294
 - Geologic maps, USGS, 380, 424
 - Geologic section, 295
 - Geologic time chart, 85
 - Geology, 1, 76, 82, 407-409
 - Geomorphic features, constructional, 133
 - Geomorphic units, classification, 136
 - Geomorphological features, 102
 - Geomorphology, 1, 102
 - Geophysical prospecting, 188, 266, 278, 279, 412
 - Geosyncline, 78, 163
 - Pacific coast, 92
 - Rocky Mountain, 93
 - Geosynclinal stage, 408
 - Geyser, 135
 - Geyserite, 34
 - Girts, timbering, 192
 - Glacial col, 121
 - Glacial delta, 124
 - Glacial deposits, 134
 - Glacial drift, 122
 - Glacial geology, 118
 - Glacial lakes, 124
 - Glacial material, 121, 122
 - Glacial plains, 137
 - Glacial striations, trough, valley, 119
 - Glaciated regions, processes and surface forms, 118
 - Glaciation, 118
 - effect on prospecting, 124
 - Glacier-laid sediments, 70
 - Glaciers, ages, 98
 - depositional, erosional features, 122
 - incorrect use of word, 116
 - main types, 118
 - Glacio-fluvial deposits, 123
 - Glaciology, 118, 122
 - Glass, volcanic, 65, 67
 - Glass gauge, boiler, 218
 - Glossary of Alaskan terms, 377
 - Gneiss, 73, 74, 288
 - Go-devil, 242
 - Goes down, float, 187
 - Goethite, 42
 - Gold, 30, 42, 51, 148, 155, 164, 165, 166, 167, 288, 315-316
 - Alaska provinces, 142

- Gold, two tier system, 411
- Gold pan, 313
- Gold poke, 315
- Gold-silver, 167
- Golden beryl, 24
- Goose neck, 202
- Gossan, 159
- Gouge, 79, 80, 148
- Grab sample, 195
- Grabens, 80, 133, 134
- Graded stream, 105
 - profile, 130
- Grand Canyon of the Colorado, 96
- Grand Canyon system, 86
- Granite, 288, 289
- Granite pegmatite, 167
- Granite porphyry, 67
- Granite-rhyolite clan, 65
- Granitization, 74
- Granodiorite, 66, 166
- Granodiorite-rhyodacite clan, 66
- Granitoid texture, 65
- Granular crystal habit, 6
- Granular dynamite, 301
- Graphite, 30, 45, 48, 53, 162
- Gravel plain placers, 157
- Gravel lease, 356
- Gravimetric methods, prospecting, 267, 412
- Gravitational settling, 140
- Gravity, specific, 8
- Gravity contour maps, 267
- Gravity faults, 79
- Graywacke, 70
- Greasy luster of minerals, 7
- Greenockite, 42
- Greisen, 289
- Grenville series, 87
- Grit, 70
- Grizzly pan, 246
- Ground, block of, 213
 - evaluating, 258
 - wet, 132
- Ground ice, 112
- Ground magnetic survey, 268
- Ground moraine, 122
- Ground patterns, 116
- Ground swells, 129
- Ground water, 103, 132
- Ground water deposits, 154
- Groundmass of rocks, 65, 83
- Groundsluicing, 183, 208
 - to trace veins, 188
- Groups of rocks, 83
- Growth in place, ice, 112
- Grubstake agreements, 171, 353
- Guano, 72
- Guide drive head, 201
- Guide fossils, 83
- Gum boots, 340
- Gypsum, 7, 30, 44, 45, 54, 57, 58
 - sedimentary, 71

H

- Habit of minerals, 5
- Hackly fracture of minerals, 8
- Half life of radioactive substances, 275
- Halite, 30, 43
- Halo, 146, 188, 280
- Hammer drill, 299, 411
- Hammer drilling, 241, 299
- Hand drill, 238, 239, 299
- Hand pump injection, 218
- Handling explosives, 303
- Handling gold, 315
- Handling misfires, 304
- Handling samples, 249
- Hanging cirque, 119
- Hanging valley, 119
 - dry, 133
- Hanging wall, of fault, 79
- Hardening of tools, 312
- Hardness of minerals, 7, 47
- Hardness scale, 7
- Hardy, blacksmithing, 308
- Heading of drift, heading rounds, 191
- Headland, winged, 131
- Headwall, trough, valley, 119
- Hearth, blacksmithing, 308
- Heat colors, 313
- Heat treatment, blacksmithing, 309, 312
- Heating minerals in closed and open tube, 15
- Heave of fault, 79
- Heave, mass wasting, 104
- Helicopter use, 415
- Heliotope, 44
- Hematite, 31, 42, 45, 49, 52, 54, 56, 147
- Hemimorphite, 31, 43, 55, 57, 59
- Hiatus, 82
- Hiddenite, 39
- High angle faults, 79
- High angle thrust faults, associated with
 - folds, 80
- High center frost wedge polygons, 112
- High explosives, 301, 302
- Highgrade ore, 139
- Hillside placers, 158
- Historical geology, 1, 82
- History of mining in Alaska, 174, 410
 - important events in, 177
- History of mining law, 343
- Hitches, timbering, 191, 192
- Hoisting swivel, 204
- Holes, caisson, 231
 - casing, in thawed ground, 243
 - drowned out, freezing down, 228
 - freeze, 337
 - open, in frozen ground, 247
 - partly thawed, partly frozen, 248
 - sprung, 307
 - tightly cribbed, 234
- Holes for blasting, types, 189, 190
 - blind, 203
 - casing of, 201
 - cleaning, 223
- Hood of batholith, 165
- Hook, bucket, 215
- Hook, spit, 132
- Horizontal distances, mapping, 290
- Horizontal ground patterns, 116

- Horn, 121
 Horn of anvil, 308
 Hornblende, 31, 49, 53, 55, 56, 64, 66
 Hornblendite, 66
 Hornfels, 74
 Horses, 151
 Horses, use of in packing, 329
 Horse radish odor in minerals, 9
 Horsts, 80, 134
 Hot cutter, 308
 Hot springs, 135, 154
 Hot wire lighter, 307
 How to build prospecting appliances, 317
 Hub, in triangulation mapping, 292
 Hudson Bay moccasins, 340
- Ice, glacial, 119
 ground, growth in place, 112
 origin of during glaciation, 99
 Ice age, 98, 99
 Ice contact deposits, 123
 Ice sheet, 118
 Ice wedge, polygon, 112
 Ice wedging, 119
 Iceberg, 119
 Iceland spar, 25
 Icing mounds, 116
 Icings and related features, 116
 Identification of minerals, chemical methods, 10
 Igneous intrusion, 62
 Igneous ore deposits, 139
 Igneous rocks, 61
 classification of, 63
 control of mineralization by, 164, 166
 original structure, 76
 table of, 67
 texture and types, 65
 Igneous shields, ancient, 137
 Ignition of mineral, 106
 Ilmenite, 31, 43, 48, 49, 166, 288
 Illinois glacial age, 98
 Immiscible liquid deposits, 145
 Impervious layers, 163
 Important events in Alaskan mining, 177, 410
 Imposed structures, 76, 77
 Impounding of mineralizing solutions, 151
 Impressed potential method, prospecting, 272
 In place discovery, 344
 Incised meanders, 110
 Incompetent rock, 77
 Indented coast, 129
 Index fossils, 83
 Index suite of economic minerals, 288
 Indicator elements or metals, 280
 Indiconite, 44
 Induced radioactivity prospecting method, 278
 Induced Polarization, 412,
 Indurated sediments, 69
 Information sources for prospector, 371, 415
 Infra-red waves, prospecting, 278
 Infusible minerals, 9
- Huebnerite, 31, 41
 Hum, 133
 Humid regions, processes, surface forms, 103
 Hungarian riffles, 320
 Huronian Period, rocks, 87
 Hyalite, 34
 Hydraulic prospecting to trace veins, 188
 Hydrologic maps, USGS, 424
 Hydrothermal deposits, 140, 147, 201
 Hydrothermal metamorphism, 73
 Hydrothermal processes, 143, 147
 Hydrothermal replacement deposits, 151
 Hypabyssal igneous rocks, 65
 Hypogene deposits, 139
 Hypothermal processes, 147
- I
- Ingots, 309
 Injected deposits, 144, 145
 Injectors, 218
 Inorganic compounds, 3
 Inselberg, 127
 Insequent stream, 105
 Intensity of metamorphism, 73
 Interglacial ages, 98
 Interior Alaska, 137
 clothing for, 340
 transportation, 321
 Interior drainage, 127
 Interior plateaus, river flat lowlands, 137
 Intersection of veins, 151
 Interrupted cycle of erosion, 103
 Intrusion, igneous, 62
 Intrusive body, size effect on metasomatism, 146
 Intrusive igneous rock forms, 61, 166
 Intrusive rocks, 61
 composition of, 146
 Invaded rock, 146
 Inversion, crystal, 5
 Inversion of relief, 135
 Inversion structures, 408
 Iodine, test for, 19
 Iridescence of minerals, 7
 Iridium, 288
 Iron, 42, 152, 154
 bog; compounds of, 71
 for blacksmithing, 309
 residual, 154
 test for, 19
 Iron bearing organic sedimentary rocks, 72
 Iron ore, Black Band, 152
 Clinton, 89
 Lake Superior, 89, 152
 Iron sulfides, oxidized compounds, 161
 Ironstone, 152
 Island, coral, 137
 tied, 132
 Island mountain, 127
 Isoclinal fold, 78
 Isostasy, 1
 Isotopes, 275

J

Jack hammer, 299
 Jackleg mountings, 300
 Jade, 31, 32, 45
 Jadeite, 32, 45
 Jamesonite, 32, 42, 48
 Jar bumper, 242
 Jars, drilling, 239
 pulling, 242
 Jasper, 288

Jointing, quarrying, 80
 types of, 80
 Joints, 80
 Joint sets, 80
 Jolly Balance, 8
 Judicial districts, Alaska, 359, 360
 Junction, discordant, 119
 Jurassic-Cretaceous deposits, 142
 Jurassic Period, 92, 93, 142

K

Kame, 124
 terrace, 124, 126
 Kansan glacial age, 98
 Kaolin, 32
 Kaolinite, 32, 57, 58
 Karren, 133
 Karst areas, 137
 Karst cycle of erosion, 132, 133
 Karst topography, 132
 Keeping records, drilling, 249
 Keewatin Period, 86
 Kemp Handbook of Rocks, 64
 Kenai Peninsula, USBM literature, 401, 431
 USGS literature, 389, 429
 Kernite, 44
 Kettle, 122
 Key to Determinative tables, 47
 Keystone drill, 237

Keystone faults, 80
 Keweenaw Period, 87
 Killarney Revolution, 87
 Kimberlite, 66, 166
 Knife edge, 121
 Knife Lake age, 86
 Knob and kettle topography, 122
 Knocking head, 241
 Kobuk copper, 176, 410
 Kodiak Island, USBM literature, 431
 USGS literature, 390, 429
 Krennerite, 40
 Kunzite, 39
 Kupferschiefer, 153
 Kuskokwim, USBM literature, 402, 431
 USGS literature, 391, 429
 Kyanite, 38, 45, 155, 163

L

Labradorite, 29
 Laccolith, 61
 Lacustrine deposits, 84
 Ladder veins, 149
 Ladders, for shaft, 217
 Lagging, 192, 226
 Lag gravel, 127
 Lagoon, 131, 136
 Lake bottom deposits, 124
 Lake bottom plains, 137
 Lake Superior copper, iron, province, 142
 Lake waters and mineral precipitation, 154
 Lakes, cave-in, 114
 consequent, 111
 Lakes and swamps, 111
 Lakeshore terraces, 111
 Lamellar crystal habit, 6
 Lamprophyre, 65, 66
 Landslide, 104
 Lapis, 133
 Lapilli, 63, 135
 Laramide Revolution, 93, 94
 Laramie group, 94
 Large cartridge, dynamite, 301
 Last Ice in relation to placers, 127
 Late magmatic deposits, 144
 Late Tertiary deposits, 142
 Lateral moraine, 121
 Laterite, 69, 154
 Laurentian gneiss, 87
 Laurentide ice sheet, 99
 Lava, 61, 135
 Lava flow plains and plateaus, 137

Lava plateaus, 135
 Law, mining history, 343
 Playfair's, 108
 Laws pertaining to lode and placer, 344, 347, 349, 419
 Laws pertaining to oil and gas, 355, 421
 Layers, soil, 282
 Lazulite, 45
 Lead, 42, 161, 164
 in radiometric prospecting, 275
 test for, 20
 Lee end of drumlin, 123
 Lease, leasehold, 354, 356
 Leasing regulations, 354, 355, 356, 421
 Leasing tract, coal, 355, 421
 Legal subdivisions, 358-360
 Lending agencies, 373
 Lenses, 163
 Lenticular veins, 148
 Lepidolite, 288, 289
 Leucite, 32, 59
 Leucocratic igneous rocks, 64
 Levees, natural, 106
 Level of drifts, 191
 Level rod, mapping, 292
 Levelling techniques, 293
 Levelman, 292
 License, types of, 355
 Licenses and taxes, 356
 Liens, 352
 Lift joints, 80
 Lifters, 191
 core, 201

- Lifting bale, 201
- Lighters used in blasting, 307
- Limbs of fold, 77
- Limburgite, 66
- Limestone, 44, 71, 288
- Limited coal license, permit, 355
- Limits, assay, 186
- Limonite, 32, 45, 49, 51, 52, 53, 56
- Line of adit, 351
- Line method, calculating drill holes, 258, 259
- Line up, small boat, 321
- Linked veins, 148
- Liquid injection and segregation deposits, 144
- Liquid oxygen explosives, 302
- Literature, see references at end of chapters and Bibliography
- Lithified sediments, 69
- Lithium, 44
- Little Ice Age, 99
- Littoral currents, 129
- Livengood chert, 90
- Llanoria province, 90
- Load metamorphism, 73
- Looming, to trace veins, 188
- Local base level, 103
- Local glaciers, 118
- Local metamorphism, 73
- Locatable minerals, 345
- Location notice, lode, 344
 - placer, 350
- Lode, 139, 148, 180, 288
 - claim size, 347, 349
 - laws pertaining to, 344, 347, 420
- Lode deposits, circumstances favorable for, 207
 - prospecting and exploring, 198
- Lode fissure deposits, 151
- Lodestone, 8, 32
- Loess, 70, 115
 - plains, 137
- Long-tom 231
- Longitudinal consequent stream, 110
- Longitudinal dune, 128
- Longshore currents, 129
- Low angle faults, 80
- Low center frost wedge polygons, 112
- Low explosives, 301
- Lowgrade ore, 139
- Lower Carboniferous epoch, 90
- Lowlands of Alaska, 137
- Lowering iron, 203
- Luminescence of minerals, 7
- Luster of minerals, 7, 46, 47

M

- Mafic igneous rocks and minerals, 63
- Magazine, dynamite, 303
- Magma, 61
- Magmatic concentration, 140, 142, 144
- Magmatic segregation, 65
- Magnesian marble, 74
- Magnesite, 32, 43, 45, 59
- Magnesium, 43
- Magnetic gradient, 413
- Magnetic methods in prospecting, 268, 412
- Magnetism of minerals, 8
- Magnetite, 32, 42, 48, 147, 166, 288
- Magnetization, mineralogy test, 17
- Magnetometer, in prospecting, 268, 412, 413
- Malachite, 33, 45, 55
- Malleable mineral, 8
- Mamillary crystal habit, 6
- Manganese, 43, 152, 155, 161
 - test for, 20
- Manganite, 33, 43, 49, 50
- Mantle, of earth, 1
- Map, assay, 195
 - base, 188, 189
 - contour, 102, 292
 - drawing of, 294
 - gravity contour, 267
 - topographic, 102, 294
 - USGS, 379, 380, 424
- Mapping, 290-294, 298
- Marathon disturbance, 90
- Marble, 45, 73, 74
- Marcasite, 33, 50, 51, 147
- Marine cycle of erosion, 131
- Marine placers, 158
- Marine sedimentary rocks, 69
- Marl, 70
- Marsh, 132
- Martensite, 312
- Mass effect, radiometric prospecting, 277
- Mass wasting, 104
- Massive crystal habit, 6
- Massive deposits, 151
- Massive structure, 148
- Master stream, 110
- Matanuska geosyncline, 409
- Match lighters for explosives, 307
- Materials, blacksmithing, 308
 - commercial, 42
- Materials brought up by burrowing animals, 188
- Matrix of rocks, 65
- Maturity, erosion cycle, 102
 - fluvial cycle, 105, 106
- Meander, incised, 110
 - stream, 106
- Measurements, 374
- Mechanical concentration of minerals, 144, 154, 156
- Mechanical origin of sedimentary rocks, 69
- Mechanical weathering, 103
- Mechanics of wave action, 129
- Medial moraine, 121
- Melanocratic igneous rocks, 64
- Members of formation, 83
- Mercury, 43, 148, 164, 316
 - province in Alaska, 142
 - test for, 20
- Mesothermal, semi-diagnostic mineral deposits, 147
- Mesozoic Epoch, 82, 92, 93, 141, 142, 408
- Metacryst, 74
- Metallic luster, 7, 46, 48
- Metallogenetic epochs, 82, 141
- Metallogenetic provinces, 141, 142
- Metals, 42, 138
 - bending of, 310

- Metals, commercial, 42
 - precious, 139
- Metamorphic agency, 73
- Metamorphic deposits, 162
- Metamorphic region, peneplaned, 137
- Metamorphic rock chart, 75
- Metamorphic rocks, 61, 72-75, 144, 288
- Metamorphic shield, ancient, 137
- Metamorphism, 73, 162
- Metamorphosed deposits, 162
- Metaquartzite, 74
- Metasomatic deposits, 146
- Metasomatic replacement, 150
- Metasomatism, 140, 143, 146
- Meteoric water, 103
- Methods in sinking shafts, 220
- Methods in using dynamite, 303
- Methods of evaluating ground, 258, 264
- Mexican onyx, 71
- Mica, 45, 288
 - group, 33
- Micaceous crystal habit, 6
- Microcline, 28, 45
- Microscopic accessories of igneous rocks, 63
- Mid-ocean Ridge, 407
- Middle-late Mesozoic deposits, 141
- Mild steel, 309
- Milky quartz, 36
- Milligal, 268
- Millsite, 352, 420
- Mimetite, 41
- Mine, 180, 191
- Mine computations, 228
- Mine shaft, 227
- Mineral, 3, 139
 - accessory, 63
 - crystallization of, 5
 - description of, 23
 - economic, 3
 - economic index suite of, 288
 - essential, 63
 - gangue, 139
 - list under consideration, 4
 - physical and chemical properties of, 6
 - rock-forming, 3
 - saturated and unsaturated, 64
- Mineral claims, 344, 345, 419
- Mineral content of igneous rock, 63
- Mineral deposits, 1, 139, 142, 144
- Mineral identification by chemical methods, 10
- Mineral paints, 155
- Mineral sources, 42
- Mineralization, control of, 163
 - mechanical and residual concentration, 154
 - recurrent shoots, 151
 - signs of, 184
- Mineralizers, 140
- Mineralogical prospecting, 188, 266, 285
- Mineralogy, 1, 3
 - determinative, 3, 46
- Mineralogy reagents, 10
- Mineraloids, 3
- Mining, 180
 - history of in Alaska, 343
 - important events, 177
 - introduction to, 343
 - unpublished theses concerning, 404, 434
- Mining claims, 343, 344, 345, 346, 351, 419
- Mining forms, 357, 422
- Mining law, 343-357, 418-421
- Mining licenses and taxes, 356
- Mining liens, 352
- Mining section, 251
- Miocene Epoch, 96
- Miogeosyncline, 408
- MIRL publications, 435
- Misfires, dynamite, 304
- Mispickel, 23
- Mississippian Period, 90, 408
- Mobile belt, 407
- Moccasins, 340
- Mohorovicic discontinuity, 1
- Molil, 194
- Molecule, 3
- Molybdenite, 33, 43, 48, 50, 53, 161, 288
- Molybdenum, 43, 165, 167
 - test for, 20
- Monadnock, 103, 107
- Monazite, 33, 54, 55, 58, 288
- Monocline, 78
- Montana group, 94
- Monzonite, 66, 166
- Monzonite-lafite clan, 66
- Moraine, 121, 122
- Morganite, 44
- Morrison formation, 93
- Mosasaurs, 95
- Mounds, frost, icing, 116
- Mountain drainage, 110
- Mountain glacier, 118
- Mountains, block, 110
 - complex, 134
 - dome, 137
 - fault block, 134, 137
 - fold, 137
- Mountains without roots, 134
- Muck, 100, 115, 189
- Mucking the hole, 223
- Mudcapping, 306
- Mudcracks, 76
- Mudflow, 104
- Mudstone, 69, 70
- Mules, use of in packing, 329
- Mullite, 38, 163
- Muscovite, 34, 45, 57, 58, 59
- Mushroom gossan, 160

N

Nap of rope, 240
 Nappes, 134
 Natrolite, 41
 Natural bridge, 133
 Natural levees, 106
 Nebraskan Glacial Age, 98
 Neck of land, 106
 Necks, 61
 Nenana gravel, 97
 Nepheline, 34, 45, 58, 59, 167
 Nepheline, syenite-phonolite clan, 65
 Nephrite, 32, 45
 Nested crater, 135
 Nested saucer basin, 137
 Net slip, of fault, 79
 Nevadan disturbance, 93
 Névé, 119
 Niccolite, 34, 35, 51, 52
 Nickel, 43, 155, 161, 288
 test for, 20
 Nickel bloom, 34
 Nickel-copper, 166
 Nickeliferous pyrrhotite, 35, 43
 Night cap, 247
 Niobium, 20

Oblique approach of waves, 129
 Oblique slip fault, 79
 Obsequent stream, 110
 Obsidian, 67
 Occupied point, mapping, 291
 Occupied station, geophysical prospecting, 269
 Occurrence of minerals, 10
 Ocean floor spreading hypothesis, 407
 Ocean waters and mineral deposits, 154
 Odor of minerals, 8
 Offshore bar, 131
 Offshore prospecting permit, 355
 Oil, 153
 Oil field, unitized, 356
 Oil and gas lease, 355, 421
 Oil pool, 153
 Oil shale, 153
 lease, 356
 Old age, cycle of erosion, 102
 fluvial cycle, 107
 Oldest observed rocks, 84
 Oligocene Epoch, 96
 Oligoclase, 29
 Olivine, 34, 44, 288
 Onyx, 44, 71
 Oolites, 70
 Oolitic crystal habit, 6
 Opal, 34, 44, 54, 55, 56, 59, 68
 Opaque minerals, 7
 Open folds, 78
 Open holes in frozen ground, 247
 Open tube, heating minerals in, 15
 reactions, 15
 Open spaces in veins, 151
 Opencutting, 208
 Optical crystal, 44
 Orange peel digger, 411

Nip, 131
 Nipple point, 219
 Non-adjusted drainage patterns, 110
 Non-competitive mining lease, coal, 355
 Non-conformity, 77
 Non-foliated metamorphic rocks, 73
 Non-nitroglycerin explosives, 302
 Non-polarizing electrodes, 271
 Non-sorted sedimentary rocks, 69
 Non-sorted stripes, 116
 Nonmetallic luster, 7, 47, 53
 Non metals, use of, 43
 Norite, 66, 166, 288
 Normal cycle of erosion, 103
 Normal fault, 79
 Normalizing of steel, 312
 NORTH commission, 410
 Northern Alaska, USBM literature, 402, 431
 USGS literature, 391, 429
 Northwestern Alaska, USBM literature, 402
 USGS literature, 393, 429
 Nose, structural, 78
 Notch, wave cut, 130
 Null, 272
 Nunatak, 121

O

Order of crystallization in igneous rocks, 64
 Ordovician period, 88
 Ore, 139, 180, 186, 195
 block of, 195
 calculating value of, 196
 dilution of, 198
 lowgrade, complex, highgrade, simple, 139
 probable, prospective, proved, 192
 when to follow, 189
 when to leave, 186
 Ore body, 150, 288
 Ore deposit, 1, 139
 mode of origin, 166
 vesicular filling, 150
 Ore mineral, 139
 Ore sample for assay, 195
 Ore shoots, 151, 180
 Organic compounds, 3, 36
 Organic origin of sedimentary rocks, 69
 Organic sedimentary rocks, 71
 Original structures, igneous, sedimentary, 76
 Ornamental minerals, 45
 Orogeny, 2, 96
 Orthoclase, 9, 28, 45, 64, 289
 Orthoquartzite, 74
 Oscillatory wave, 129
 Other agencies to aid prospector, 373
 Out of adjustment, drainage pattern, 110
 Outlier, 134
 Outside, meaning of expression, 176
 Outwash deposits, 123
 Overburden drilling equipment, 412
 Overflow ice, 116
 Oversaturated igneous rocks, 64
 Overthrust fault, 80, 134
 Overturned fold, 78

Oxbow lake, 106
 Oxidation, process, 141
 color of products, 161
 superficial, 144

Oxidation and supergene enrichment, 159
 Oxides, 23
 Oxidized compounds, 161
 Oxidizing flame, 10

P

Pacific Coast geosyncline, 92
 Pacific Mountain system in Alaska, 364
 Pacific type coast, 129
 Packboards, packsacks, 328
 Packsack drill, 201
 Paddle, clean-up, 315
 Pahoe-hoe, 135
 Paints, mineral, 155
 Paleocene Epoch, 96
 Paleontology, 1
 Paleozoic era, 82, 88, 91, 142
 Palisades, 136
 Palladium, 288
 Pan and rocker, 313
 Pannier, 329
 Panning to trace veins, 188
 Panning with a grizzly, 246
 Parallel drainage, 108
 Parallel unconformity, 77
 Parallel wire in electrical prospecting, 272
 Parasitic cone, 135
 Parent material, 282
 Parent rock, 139
 Parka, 340
 Parting in minerals, 8
 Partly thawed, partly frozen holes, 248
 Pass, 107
 Patenting claims, 353, 420
 Paternoster lake, 119
 Patronite, 43
 Patterned ground, 116
 Pay horizon, 251
 Paystreak, 156
 Pearlite, 312
 Peat, 72, 100, 153
 Pediment, 128
 Pediplain, 128
 Pegmatite, 67, 140, 288, 289
 Pelly gneiss, 87
 Penberthy injector, 218
 Pendants, roof, 147
 Peneplain, 103, 107
 Peneplane, 103
 Peneplaned regions, 137
 Penetrating edge of bit, 311
 Pennsylvanian Period, 90, 91
 Pentlandite, 34, 51
 Perched boulders, 123
 Perched water table, 132
 Peridot, 34, 44, 288
 Peridotite, 66, 166, 288
 Peridotite-basalt clan, 66
 Periglacial cycle, 111
 Periglacial effects, 99
 Periods of time, 83
 Perknite, 66
 Perknite-augitite clan, 66
 Permafrost, 100, 104, 112
 Permafrost table, zones, 112
 Permian Period, salt basin, 91

Permissible dynamite, 301
 Permit, limited, offshore prospecting, 355
 Permo-Triassic epoch, 83, 142
 Persilicic igneous rocks, 63
 Petrogenesis, 61
 Petrography, 61
 Petrology, 1, 61
 Phanerite, 65
 Phanerozoic Eon, 82, 88
 Phase angle, geophysical prospecting, 413
 Phenocrysts, 65
 Phlogopite, 35
 Phosphate-bearing sedimentary rocks, 72
 Phosphates, 152
 lease, 356
 Phosphorescence of minerals, 7, 278
 Phosphors, 276
 Phosphorus, test for, 20, 21
 Photogeology, 297
 Phyllite, 74
 Physical controls of mineralization, 164
 Physical properties of minerals, 6
 Physiographic provinces, 136
 Physiography, 1, 102
 Picotite, 288
 Piedmont alluvial plain, 110
 Piedmont glacier, 118, 122
 Piedmont plain, 136
 Piedmont slope, 128
 Piercing to trace veins, 188
 Pierre Shale, 94
 Pig iron, 309
 Pigments, 45
 Pin and box, 239
 Pingo, 116
 Pipe clamp, 202
 Pipe tongs, 241
 Piracy, stream, 107
 Pisolites, 70
 Pisolithic crystal habit, 6
 Piston drill, 299
 Pitchblende, 35, 288
 Pitches and flats, 149
 Pitchstone, 67
 Pitted outwash, 123
 Placer, 107, 141, 156-159, 180
 relation to glacial deposits, 126
 Placer bit, 239
 Placer claims, 350
 laws pertaining to, 344, 349, 420
 Placer deposits, prospecting and exploring, 207
 drilling, 236
 Plagioclase feldspars, 29, 45, 64
 Plains, 127, 131, 135, 136, 137
 Piedmont alluvial, 110
 Plane, crystal, 5
 fault, 79
 Plaster, cement, 45
 Plaster tablet, reactions, 16
 Plateau, interior, 137
 lava, 135

- Plateau type faults, 79
- Platform stage, tectonic cycle, 408
- Platinum, 35, 43, 51, 166, 288
- Playa, playa lake, 128
- Playfair's law, 108
- Pleistocene Epoch, 98
- Pleistocene glaciation in Alaska, 117
- Pleonaste, 288
- Pliocene Epoch, 96
- Plucking, glacial, 119
- Plug, 61
 - drilling, 245
 - structural, 78
- Plug bit, 204
- Plums, mining, 199
- Plunge hard steel, 313
- Plunge of axis, 78
- Plunge pools, 111
- Plunging fold, 78
- Plutonic igneous rocks, 65
- Pneumatolytic metamorphism, 73
- Pocket beaches, 131
- Points, for thawing, 219
 - hammer for, 219
 - using, 222
- Poke, gold, 315
- Pole lagging, timbering, 192
- Pole riffles, 320
- Poljes, 133
- Polygon, 112, 116
- Polymorphism, crystal, 6
- Ponokean Revolution, 87
- Pool, oil, 153
- Porcupine boiler, 217
- Pore space fillings, 150
- Porphyritic texture, 65, 74
- Porphyroblast, 74
- Porphyry, 65, 67
- Portable drill, 201
- Positive areas, 90
- Post glacial times, 126
- Post offices in judicial districts, 359
- Posts, timbering, 192, 226
- Potassium lease, 356
- Potentiometer, use, 272
- Pottery, 45
- Power churn drill, 237
- Power drilling, 299
- Practical effect of glaciation on prospecting, 124
- Precambrian Era, 82, 84, 87, 142
- Precious metals, 139
- Precious opal, 34
- Precious serpentine, 37
- Preliminaries to prospecting, 180
- Pre-Ordovician age, 83
- Preparation in fluvial cycle, 103
- Preparation of charges, 304
- Preparatory work in use of dynamite, 303
- Pressure gauge, boiler, 218
- Primacord, 302
- Primary breakage, 304
- Primary deposits, 139
 - in sedimentary rocks, 142
- Primary epigenetic deposits, 145
- Primary halo, 280
- Primary rocks of Europe, 96
- Primary triangulation net, 292
- Primers, dynamite, 303
- Probable ore, 192
 - calculating value, 198
- Procedure in clean-up, 315
- Procedure in using dynamite, 303
- Process of drilling, 242
- Processes and surface forms, arid lands, 127
 - coastal areas, 129
 - cold lands, 111
 - glaciated regions, 118
 - humid regions, 103
 - in underground solution areas, 132
- Profile of equilibrium, 130
- Profiles, drill hole, 295
- Proglacial deposits, 123
- Progradation, coastline, 131
- Properties of crystals dependent upon light, 7
- Properties of high explosives, 302
- Properties of minerals, 5
- Proportional weights, 256
- Prospect, 180
- Prospect appliances, how to build, 317
- Prospect boilers, 217
- Prospecting, 171, 180, 184
 - auxiliary techniques, 290
 - axiom, 189
 - effect of glaciation on, 124
 - electrical, 271, 413
 - electromagnetic, 274, 275, 413
 - financing of, 171
 - geochemical, 280, 415
 - geophysical, 266, 278, 412
 - gravimetric, 267
 - gravitational, 412
 - Induced Polarization, 414
 - justification for, 184
 - lodes, 184, 198
 - magnetic, 266, 268, 269, 270, 412
 - mineralogical, 266, 285
 - offshore permit for coal, 355
 - placer, 207, 355
 - present status of, 172
 - radiometric, 275
 - seismic, 266, 412
- Prospecting sites, 351
- Prospecting with dogs, 323
- Prospecting with Helicopter, 415
- Prospecting with snowmobile, 416
- Prospective ore, 192
- Prospector, 171
 - information and aid sources, 371, 423
- Prospector drill, 237
- Proterozoic Era, 82, 84
- Protore, 139
- Proustite, 35, 52, 53, 54
- Proved ore, 192
 - calculating value of, 197
- Provinces, 136, 137
 - metallagenetic, 141, 142
- Pseudomorph, 6
- Psilomelane, 35
- Pterodactyls, 95
- Publications pertinent to prospecting, 379, 406, 424-436
- Puddling furnace, blacksmithing, 309
- Pull piece, 202

Pull wire fuse lighter, 307
 Pulley, crown sheave, 237
 Pulling jars, drilling, 241
 Pumice, 67
 Punching metal, 310
 Pup, 156
 Push moraine, 122
 Pyargyrite, 35, 48, 49, 52, 53, 54
 Pyramid cut round of holes, 191
 Pyrite, 35, 51, 288

Pyroclastic material, 67
 Pyroclastics, 61, 135
 Pyrolusite, 36, 43, 48, 53
 Pyrophyllite, 163
 Pyrope, 288
 Pyroxene, 147
 to distinguish from amphibole, 64
 Pyroxenite, 66, 166
 Pyrrhotite, 36, 147, 288
 nickeliferous, 35, 43

Q

Qualitative tests for elements, 17
 Quarry bar, drill, 300
 Quarrying, 80
 glacial, 119
 Quartered sample, 195
 Quartz, 7, 9, 36, 43, 44, 45, 55, 58, 60,
 166, 288, 289
 bull, 194

Quartz diorite, 66, 167
 Quartz-diorite-dacite clan, 66
 Quartz latite, quartz monzonite, 66
 Quartz monzonite-quartz latite clan, 66
 Quartzite, 70, 73, 74
 Quaternary period, 96, 98-100, 142
 Quick seal plugs, use with explosives, 306

R

Radford factor, in calculations, 250
 Radial drainage, 108
 Radiated crystal habit, 5
 Radioactive dating, 84, 99
 Radioactivity in prospecting, 275
 induced, 278
 Radiometric prospecting, 275
 Radium, 148
 Radon effect, radioactivity, 277
 Rafted erratics, 124
 Raindrop imprints, 76
 Rank of metamorphism, 73
 Rank of coal, 153
 Rapids, 107
 Raw materials for blacksmithing, 308
 Reactions on charcoal, 10, 12
 Reactions on plaster tablet, 16
 Reactions, other mineralogy, 17
 Reading geologic maps, aerial photographs,
 295
 Reagents, conditioning, 285
 needed for mineral identification, 10
 Realgar, 36, 54, 147
 Reamer shell, drill, 201
 Receiver tank, 300
 Recent Epoch, 98
 Recent placers, 157, 158
 Recent streams, 110
 Reconnaissance, 182
 Recording districts, 259, 260
 Records, keeping, 249
 Recovering gold, 315
 Recovery tap, 205
 Rectangular drainage, 108
 Recumbent folds, 78
 Recurrent mineralized shoots, 151
 Recurved spit, 132
 Red beds, 69
 Reducing flame, 10
 Reef, 72, 136, 149
 Reference interval, choice of, 256
 Refraction method, seismic prospecting, 412
 Refractories, 45
 Regional base level, 103

Regional metamorphism, 73
 Regolith, 69
 Rejuvenation, fluvial cycle, stream, 105
 Rejuvenation of base level, erosion, 103
 Relationship of streams, 107
 Relief, inversion of, 136
 Relief features, order of, 102
 Relief of an area, 102, 103
 Removal by running water, 104
 Replacement, 140, 143, 150
 Resequent stream, 110
 Residual concentration, 144, 154
 Residual deposits, 141, 144
 Residual iron, 154
 Residual magma, 144
 Residual nickel, 154
 Residual sedimentary rocks, 69
 Resinous luster, 7
 Resistivity, prospecting, 273
 Reticulated crystal habit, 5
 Reverse fault, 79
 Revolutions, 83, 87
 Rhodochrosite, 36, 54, 147
 Rhodonite, 36, 54, 55, 57, 58
 Rhyodacite, 66
 Rhyolite-porphry, 67
 Rias, 131
 Ribbon structure, veins, 148
 Ridge, 105, 131
 fault, 80
 in fluvial cycle, 105
 Riegels, 119
 Riffles, 318, 320
 Rift valley, 134, 135
 Rim, bedrock, 207
 Ring of fire, 96
 Ripple marks, 76
 River bar placers, 157
 River flat lowlands, Alaska, 137
 Riveting metal, 310
 Roasted sample, 194
 Rouche moutonné, 119
 Rock bits, 239
 Rock, country, 139
 Rock crystal, 36, 44

- Rock flour, milk, 122
 - Rock formation, cycle of, 75
 - Rock forming minerals, 3
 - Rock forms, igneous, 61
 - Rock glacier, 104
 - Rock regions, peneplaned, 137
 - Rock units, 82
 - Rocks, classification, study of, 61
 - competent, 77
 - correlation of, 84
 - geologic division of, 82, 83
 - igneous, 61
 - metamorphic, 73
 - sedimentary, 69
 - wind faceted, 127
 - Rocker, how to build, 318
 - use of, 313, 314
 - Rocky Mountain geosyncline, 93
 - Rocky Mountain trough, 94
 - Rod, drill, 201
 - Rod, sizes, 205
 - Saddle of ridge, 107
 - Saddle reefs, 149
 - Safety clamp, 203
 - Safety fuse, dynamite, 302
 - Safety valve, boiler, 218
 - Salic minerals, 63
 - Saline taste of minerals, 9
 - Salt plugs, 78, 267
 - Salts, 43, 71
 - Saltpeter, Chile, 44
 - Sample, analysis of, 283
 - handling, 249
 - sediment, 415
 - soil, 285
 - types, 194, 195, 285, 415
 - water, 285
 - Sample sheet, 194
 - Sampling equipment, 283
 - Sampling open holes in frozen ground, 247
 - Sampling ore for assay, 195
 - Sampling procedures and calculating results, 194
 - Sampling sediments, soil, water, 281, 415
 - Sand, 153
 - black, 31, 33, 137, 314
 - ruby, 30, 157, 314
 - Sand dunes, 70
 - Sand line, 237, 242
 - Sand pump, 242
 - Sandstone, 69, 94, 153
 - Sangamon Interglacial age, 98
 - Sapphire, 27, 44, 288
 - Satin spar, 30, 71
 - Saturated igneous rocks, 64
 - Saturated minerals, 64
 - Sawbuck, 334
 - Scab, timbering, 192
 - Scale of hardness, 7
 - Scale of fusibility, 9
 - Scarfing metal, 310
 - Scarp, fault, fault line, 79
 - in black mountains, 134
 - veelite, 37, 43, 57, 288
 - vee, 73, 74, 288
 - Rodman, in mapping, 292
 - Rollled sample, 195
 - Roof of batholith, 165
 - Roof pendants, 147, 166
 - Rope, nap of, 240
 - Rope socket, drilling, 239
 - Rose beryl, 24
 - Rose quartz, 36
 - Rotational fault, 79
 - Rotational firing of explosives, 304
 - Rotary inversion of crystal, 5
 - Rounds, cribbing, 191, 226
 - of holes, 189, 191
 - Rubellite, 44
 - Ruby, 44, 288
 - Ruby sand, 30, 157, 314
 - Ruby silver, 147
 - Rudaceous sedimentary rocks, 69
 - Running water, transportation by, 104
 - Rutile, 37, 43, 48, 49, 50, 52, 54, 55, 57, 288
- S
- Schist, Birch Creek, 83, 408
 - Vishnu, 86
 - Schistosity, 62, 163
 - Scintillometer, 276
 - Scouring, glacial, 119
 - Sea arch, cave, cliff, 130
 - Sealing the shaft, methods, purposes, 226
 - seasonal frost, 112
 - Second Judicial district, 359
 - Second order relief features, 102
 - Second tier claims, 350
 - Secondary breakage, 304, 306
 - Secondary deposits, 139
 - Secondary enrichment, 159
 - Secondary halo, 280
 - Secondary processes of deposition, 143
 - Secondary rocks in Europe, 96
 - Secondary sulfide enrichment, 141, 160
 - Secretions, 70
 - Seclite mineral, 8
 - Sections, geologic, 295
 - Sediment sampling, 415
 - Sedimentary clay, 153
 - Sedimentary copper, 153
 - feruginous, 71
 - Sedimentary deposits, chemical origin, 71
 - Sedimentary manganese, 152
 - Sedimentary quartzite, 70
 - Sedimentary rock regions, peneplaned, 137
 - Sedimentary rocks, 61, 69
 - carbonaceous, 72
 - of chemical origin, 70, 71
 - of mechanical origin, 69
 - of organic origin, 71
 - of residual origin, 69
 - phosphate bearing, 72
 - table of, 72
 - Sedimentary salts, 71
 - Sedimentary uranium and vanadium, 153
 - Sedimentation, 143, 152
 - Sediments, glacier laid, 70
 - organic, 71
 - terrestrial, 83

- Sediments, waterlaid, 69
 - windlaid, 70
- Segregated mineral deposits, 144, 145
- Seismic prospecting, 266, 412
- Selenides, 147
- Selenite, 30, 71
- Selenium, test for, 21
- Self dumping buckets, carriers, 215
- Self potential, electrical prospecting, 271
- Selva, fault, 79, 148
- Semi-precious minerals, 45
- Sericite, 34
- Series of rocks, 83
- Serpentine, 37, 45, 53, 55, 56, 73, 74, 288
- Serpentinite, 74
- Sets, bearing, 192, 226
- Sets of joints, 80
- Seward Peninsula, USBM literature, 402, 431
- USGS literature, 393, 429
- Shafts, 189, 190, 211, 215, 226, 228
- Shale, 69, 72
 - oil, 153
 - oil, leasing, 356
- Shallow drain, 182
- Shaped charges, 306
- Sharpening of tools, 311
- Shatter breccia, 150
- Shear boards, 208
- Shear zones, 80, 148
- Shears, complementary, 186
- Sheet jointing, 80
- Sheeted veins, 148
- Sheetflood, 127
- Shelter, camp, 321, 331
- Shield, ancient, 137
 - Canadian, 86
 - PreCambrian, 84
- Shield volcano, 62
- Shoe joint, 241
- Shoe pacs, 340
- Shoes, trail, 326
- Shore features of glacial lakes, 124
- Shore profile, 130
- Shoreline, 129
 - crenulate, 131
 - elevated, 132
- Sickened mercury, 316
- Siderite, 37, 49, 52, 53, 56, 71, 147
- Signs of mineralization, 71, 182
- Silica, 71
 - test for, 21
- Siliceous chemical sedimentary rocks, 71
- Siliceous igneous rocks, 63
- Siliceous organic sedimentary rocks, 72
- Siliceous sinter, 71
- Silicic rocks, 63
- Silky luster of minerals, 7
- Sillimanite, 45, 163
 - group, 37, 45, 58, 59, 163
- Sills, 61
 - in timbering, 192
- Silt, 115
- Siltstone, 69
- Silurian Period, 89, 147
- Silver, 38, 43, 49, 50, 147, 161, 164, 166
 - test for, 21
- Silver amalgam, 316
- Silver-lead, 142, 148
- Similar folding, 78
- Simple fissure veins, 148
- Simple ore, 139
- Simple structures, 136, 137
- Single jacking, 299
- Sink, 133
- Sinker, 299
- Sinker bar, drilling, 239
- Sinking caissons, 229
- Sinking equipment, 216
- Sinking shafts, in frozen ground, 215
 - in thawed ground, 228
 - in wet ground, 229
- Sinking tightly cribbed holes, 234
- Sinter, 71
- Siwashing, 330
- Size of intrusive body, effect of, 146
- Sizes of churn drill tools and casings, 376
- Skarn, 147
- Sketchboard, mapping, 290
- Skutterudite, 38, 50
- Slabbing round, 191
- Slack tub, blacksmithing, 308
- Slate, 73, 74
- Sleds, types of, 323
 - use in freighting, 324
- Slickensides, 80
- Slide, sliderock, 104
- Slip of fault, 79
- Slip-off slope, 106
- Slippe, 134
- Sloping ground patterns, 116
- Slaugh, 106
- Sluice, 315
- Sluice box, 318
- Sluicfork, 208
- Sludge box, 204, 320
- Small cartridge, dynamite, 301
- Smithsonite, 38, 43, 55, 57, 59
- Smoky quartz, 36
- Snakeholing, 306
- Snow boats, 340
- Snowfencing for water supply, 211
- Snowfield, 119
- Snowmobile, 416
- Snowshoes, 326, 327
- Soapstone, 40, 163
- Sodalite, 36, 38, 39
- Sodium, lease, 356
 - test for, 21
- Sodium amalgam, 316
- Soil layers, 282
- Soil profile, 281
- Soil sampling, kit, 239
 - in geochemical prospecting, 281, 285, 415
- Solids factor in thawed ground, 250
- Solifluction, 104, 111, 115
- Solubility of minerals, 9
- Solution cavity fillings, 150
- Solution subsidence, 133
- Sorted sediments, 69
- Sorted stripes, 116
- Sour taste of minerals, 9
- Sources, minerals, 42
 - information, aid for prospectors, 371-373, 423
- Sourdough starter, 417

- Southeastern Alaska, 137
 - clothing for, 341
 - transportation, 321
 - USBM literature, 403, 431
 - USGS literature, 394, 429
- Spalling, glacial, 119
- Specific gravity, 8
- Specular hematite, 147
- Sphalerite, 38, 43, 49, 52, 53, 56, 57, 147, 288
- Sphene, 40
- Spine, volcanic, 135
- Spinel, 288
- Spit, 132
- Spit of fuse, 306
- Spitter, lighter, 307
- Splashing to trace veins, 188
- Splashing with a dam, 209
- Splintery fracture, 8
- Spodumene, 39, 44, 55, 56, 58
- Sporadic zone of permafrost, 112
- Spring core drill, 201
- Spring pole drill, 239
- Spring water, 208
- Springs, Hot, 135
- Sprung hole, 307
- Spudding action, 237
- Square section, drill tools, 239
- Square-up holes, 191
- Stabilized dunes, 128
- Stack, sea, 130
- Stags, 340
- Stages of rocks, 83
- Staking claims, 343, 344, 419
- Staking-in another person, 349
- Stalactites, stalagmites, 71
- Stalactitic crystal habit, 6
- Stampede, 180
- Standpipe, 202
- Stannite, 39, 48, 50
- Star drill, 237
- State Division Mines, Geology, 372, 407, 423
- State lands, leasing, 354, 419
- State publications, 405, 432
- Static metamorphism, 73
- Station, magnetic survey, 269
- Station, mapping, 292
- Stationary dunes, 128
- Staurolite, 39, 53
- Steam hose, 219
- Steam injector, 218
- Steam point, 219
- Steam thawing equipment, 219
- Steatite, 40
- Steel, blacksmithing, 309, 312, 313
- Stem drilling, wrenches, 239
- Stemming of explosives, 305
- Step, of anvil, 308
- Step fault, 79
- Steproes, 135
- Stereo-pair, aerial photographs, 297
- Stibnite, 9, 39, 42, 48, 50, 147
- Stick of dynamite, 301
- Stilbite, 41
- Stinger, drill mounting, 300
- Stock, 61
- Stockworks, 149
- Stop cock, boiler, 219
- Stope cut holes, 190
- Stoper, 299
- Stoping, 180, 193
- Storage, caps and high explosives, 303
- Storm waves, 129
- Stoss end of drumlin, 123
- Straight dynamite, 301
- Strand plain, 131
- Strath, 106
- Stratified drift, 123
- Stratigraphic control of mineralization, 163
- Stratigraphic throw faults, 79
- Stratigraphic traps, 78
- Stratigraphy, 1
- Streak of minerals, 7, 47
- Streak plate, 7
- Stream, 105, 107, 110
 - capture, piracy, 107, 108
- Stream channel, 106
- Stream placer, 156
- Stream relationship, 107
- Streaming down, sluice, 315
- Strength of high explosives, 302
- Striations, glacial, 119
- Strike of structure, 77
- Strike slip faults, 79
- String of tools, 239
- Stripes, patterned ground, 116
- Strontianite, 39, 44, 55, 57, 59
- Strontium, 44
 - test for, 21
- Structural control, 151
- Structural control of mineralization, 163
- Structural feature of faults, 134,
- Structural feature of vein fillings, 148
- Structural fracture, 78
- Structural geology, 1, 76
- Structural terrace, 78
- Structural throw, of faults, 78
- Structural trap, 78
- Structural unconformity, 76
- Structure, control by, 151
 - coral, 136
 - determination of by seismic methods, 267
 - disordered, 136, 137
 - folded, faulted, 137
 - imposed, 76
- Structure of chemical sedimentary rocks, 70
- Structure of igneous and sedimentary rocks, 76
- Structure of invaded rocks, 146
- Structures, original, 76
 - simple, 136
- Stulls, 190, 224
- Sub ages of glaciation, 98
- Subdivisions based on geography and geology, 360
- Subdivisions, USBM, 361
 - USGS, 360
- Sub epochs of Pleistocene, 98
- Sublimates, 146
 - on charcoal, 10, 12
- Sublimation, 143, 146
- Submarine placer, 159
- Submergent coast, 129, 130
- Submetallic luster, 7, 47
- Subsequent stream, 110
- Subsiliic igneous rock, 63

- Sulfide enrichment, 141
- Sulfur, 39, 43, 56, 57, 152
 - test for, 21
- Sulfurous odor of minerals, 8
- Summary of events in formation of mineral deposits, 139
- Summary of surface prospecting and exploration methods, 186
- Sundance formation, 93
- Superficial oxidation, 144
- Supergene deposits, 139
- Supergene enrichment, 144, 159
- Superglacial till, 122
- Superposed drainage, 110
- Superposed streams, 96
- Supratenuous folding, 78
- Surf, 129
- Surface features of the land, 102
- Surface geologic mapping, 294
- Surface prospecting, summary, 186
- Surfaces, equipotential, 273
- Surveying and mapping, 290
- Surveys in prospecting, 268
- Susitna, USBM literature, 401
 - USGS literature, 386
- Swage, blacksmithing, 308
- Swamps, 111
- Swash, wave, 129
- Sweater, 222
- Swell factor, 228
- Swing round of holes, 191
- Syenite, 67, 167
- Syenite-trachyte clan, 65
- Sylvite, 39, 44, 54, 55, 57, 58
- Symmetry, crystal, 5
- Symmetrical fold, 78
- Syncline, 77
- Synclinalorium, 78
- Syngenetic deposits, 139
 - primary and secondary processes, 143
- System of joints, 80
- System of rocks, 83

T

- Table of igneous rocks, 67
- Table of metamorphic rocks, 75
- Table of sedimentary rocks, 72
- Tabular crystal habit, 6
- Tachylite, 67
- Taconite, 155
- Talc, 7, 39, 57, 58, 163
- Talik, 112
- Talus, 104
- Tamping pole, use with explosives, 304
- Tantalite, 40, 288
- Tarn, 119
- Tarnish of minerals, 7
- Taste of minerals, 9
- Taxes, 356
- Techniques and auxiliary prospecting equipment, 290
- Techniques and equipment, camp, 323
- Tectonic breccia, 70
- Tectonic cycle, 408
- Tectonics, 407, 408
- Telescoping sluice boxes, 318
- Tellurides, 40, 48, 49, 50, 51, 147
- Tellurium, test for, 21
- Tempered martensite, 312
- Tempering tools, 312
 - temperature-color relationship, 313
- Tenacity of minerals, 8
- Tennantite, 40
- Tension cracks, 149
- Terrace, altiplanation, 116
 - lakeshore, 111
 - placer, 157
 - stream, 107
 - structural, 78
 - wavecut, 130
- Terrestrial sedimentary rocks, 69
- Terrestrial sediments, 83, 84
- Territorial (State) publications, 405
- Tertiary Period, 95, 96, 97, 142
 - deposits, 142
- Test, bead, for minerals, 11
 - chemical, for minerals, 10
- Test, foraminifera, 71
- Test pits to trace veins, 188
- Tetrahedrite, 40, 42, 48, 49
- Texture of chemical sedimentary rocks, 70
- Texture of igneous rocks, 65
- Thawed ground, 112
 - cased holes in, 243
 - sinking shafts in, 228
- Thawed holes, calculating value, 250
 - partly frozen, 248
- Thawed streak, 112
- Thawing, methods and techniques, 220
- Thermal maximum, 98
- Thermal metamorphism, 75
- Thermokarst drainage, 114
- Thermokarst features, 132
- Thermokarst mounds, pits, topography, 114
- Third Judicial district, 359
- Third order relief features, 102
- Thorianite, 288
- Thorite, 288
- Thorium effect, radioactivity, 277
- Three point method, calculating drill holes, 258, 260
- Three-timber sets, 192
- Throw, of fault, 79
- Thrust, in mass wasting, 104
- Thrust fault, 80
- Tied Island, 132
- Tightly cribbed holes, 234
- Till, tillite, 70
- Till, glacial, 122
- Tilt angle, geophysical prospecting, 413
- Timbering, 190, 192, 226
- Time, geologic division of, 82, 83, 84
 - of "great dying", 95
- Time-constant, 276
- Time domain, I. P., 414
- Time-rock units, 82
- Time table, geologic, 85
- Timer for explosives, 307
- Timiskaming age, 86
- Tin, 43, 148, 165, 167
 - test for, 22

- Tin-tungsten, 167
 Tinstone, 25
 Tinder group, 83
 Titanite, 40, 53, 55, 56, 57, 58, 59
 test for, 22
 Titanium, 43
 Tombolo, 132
 Tool steel, 309
 Tools, 239, 240-242
 blacksmithing, 307
 fishing, 242
 for churn drill, sizes, 376
 sharpening, 311
 tempering of, 312
 to prevent sticking of, 242
 Tools and accessories, 215, 239, 240-242
 Top puller, drilling, 241
 Topaz, 7, 44, 147, 288, 289
 Topographic effect, radiometric prospecting, 277
 Topographic map, 102, 294
 USGS, 379
 Topography, 102, 114, 119, 122, 127, 132
 Topset beds, 76
 Touch of minerals, 8
 Tourmaline, 40, 44, 45, 53, 55, 56, 58, 60, 147, 288
 Tracing float, veins, 186, 188
 Trail shoes, trailers, 326
 Translucence of minerals, 7
 Transparency of minerals, 7
 Transporting power of stream, 105
 Transportation, in erosion cycle, 103, 104
 for prospector, 321, 415
 of explosives, 303
 Transportation routes in Alaska, 368
 Transverse dunes, 128
 Transverse riffles, 320
 Trap rock, 66
 Traps, stratigraphic, structural, 78

 Traverses, in mapping, 294
 Traversing, 293
 Travertine, 45, 71
 Treadwell Mines, 174
 Treatment of amalgam, 315
 Treatment of mercury, 316
 Trellis drainage, 108
 Tremolite, 40
 Trenching to trace veins, 188
 Trend of axis, 78
 Triangle method, calculating drill holes, 258-262
 Triangular facets, 110
 Triangulation, in mapping, 290, 293
 Triangulation net, 292
 Triassic Period, 92
 Tributary, stream, 105
 Trimming holes, 190
 Tripoli, 72, 155
 Trough, fault, 80
 headwall, 119
 wave, 129
 Try cocks, boiler, 219
 Tuff, 67, 135
 Tundra plains, 136
 Tungsten, 43, 165, 167
 test for, 22
 Tunnel, 133, 191, 351
 Tunnel sites-prospecting sites, 351
 Turning bar, 219
 Tuyere, 308
 Twinning albite, 29
 Twinning crystal, 6
 Two point method, calculating drill holes, 258, 262
 Two tier system for gold, 411
 Type of agency in metamorphism, 73
 Types of high explosives, 301
 Types of igneous rocks, 65
 Tyrannosaurus Rex, 95

 U
 Unitized oil field, 356
 Unpublished theses dealing with Alaskan mining, University of Alaska, 404, 434
 Units of time, time-rock, rock, 82
 Unsaturated minerals, 64
 Unsorted sediments, 67
 Upland, fretted, 119
 Uplift, 105
 dome, 137
 initial, 134
 Upper barren zone, 164
 Upper Carboniferous Epoch, 90
 Upsetting, blacksmithing, 310
 Uraninite, 35, 41, 48, 49, 52, 53
 Uranium, 153, 161, 167
 in equilibrium, 275
 sedimentary, 153
 test for, 22
 Use of explosives, 301
 Use of metals, 42
 Use of non-metals, 43
 Use of pan and rocker, 313
 Uvalas, 133

V

- V cut round, drilling, 189, 191
- Valley, 105, 133, 134
 - drowned river, 131
 - u-shaped, 119
- Valley glacier, 118, 119
- Valley headwall, 119
- Valley sink, 133
- Valley train, 123
- Values, 374
- Vanadinite, 41, 54, 57
- Vanadium, 43, 153
 - test for, 22
- Variscan Ranges, 90
- Varved deposits, 111
- Varves, 111, 124
- Vegetation changes, tracing veins by, 188
- Vein, apex, 348
 - goes down, 187
- Vein filling, 147
- Veins, 148, 149
 - intersection of, 151

- Wad, 43, 152
- Wall controlled shoots, 151
- Walls, assay, 186
- Wallrock, 139
- Warping, 77
- Wash, 104, 127
- Wash tee, 201
- Washed drift, 123
- Waskey Act, 346
- Wastage, area of, 119
- Waste ditch, 208
- Water, 132, 208
 - erosion by, 127
 - test for, 22
- Water measurement, in frozen ground, 248
- Water needed for drilling, 205
- Water resistance of high explosives, 302
- Water rights, 352, 420
- Water sampling, geochemical prospecting, 281, 285
- Water table, 103, 132
- Water swivel, 201
- Waterfalls, 107
- Watergap, 110
- Waterlaid sediments, 69
- Watershed, 105
- Wave, features, mechanics, 124, 129, 130
- Wearing surface of bit, 311
- Weathering, 73, 103
- Wedge cut round, 189, 191
- Yarmouth Interglacial age, 98
- Young platform stage, tectonic cycle, 408
- Youth, in erosion cycle, 102
 - in fluvial cycle, 105

- Zeolite group, 41, 54, 58, 59
- Zinc, 43, 155, 161, 165
 - test for, 22
- Zincite, 41, 57
- Zircon, 41, 44, 55, 56, 58, 60, 288

- Veins, tracing of, 186, 188
- Ventifacts, 127
- Verd antique, 37
- Vermillion Range, 86
- Vertical distances, mapping, 292
- Vertical tectonics, 408
- Vesicles, 67, 150
- Vesicular filling ore deposits, 150
- Vishnu Schist, 86
- Vitreous luster of minerals, 7
- Vitrophyre, 67
- Volatile substance, 10
- Volcanic breccia, 67, 70, 135, 150
- Volcanic cone, 135, 137
- Volcanic forms, 134, 135
- Volcanic glass, 65, 67
- Volcanic igneous rocks, 65
- Volcanic tuff, 67, 135
- Volcano, 62, 135, 150
- Volume bucket, 242
- Volume loose, 228, 231
- Vug, 147

W

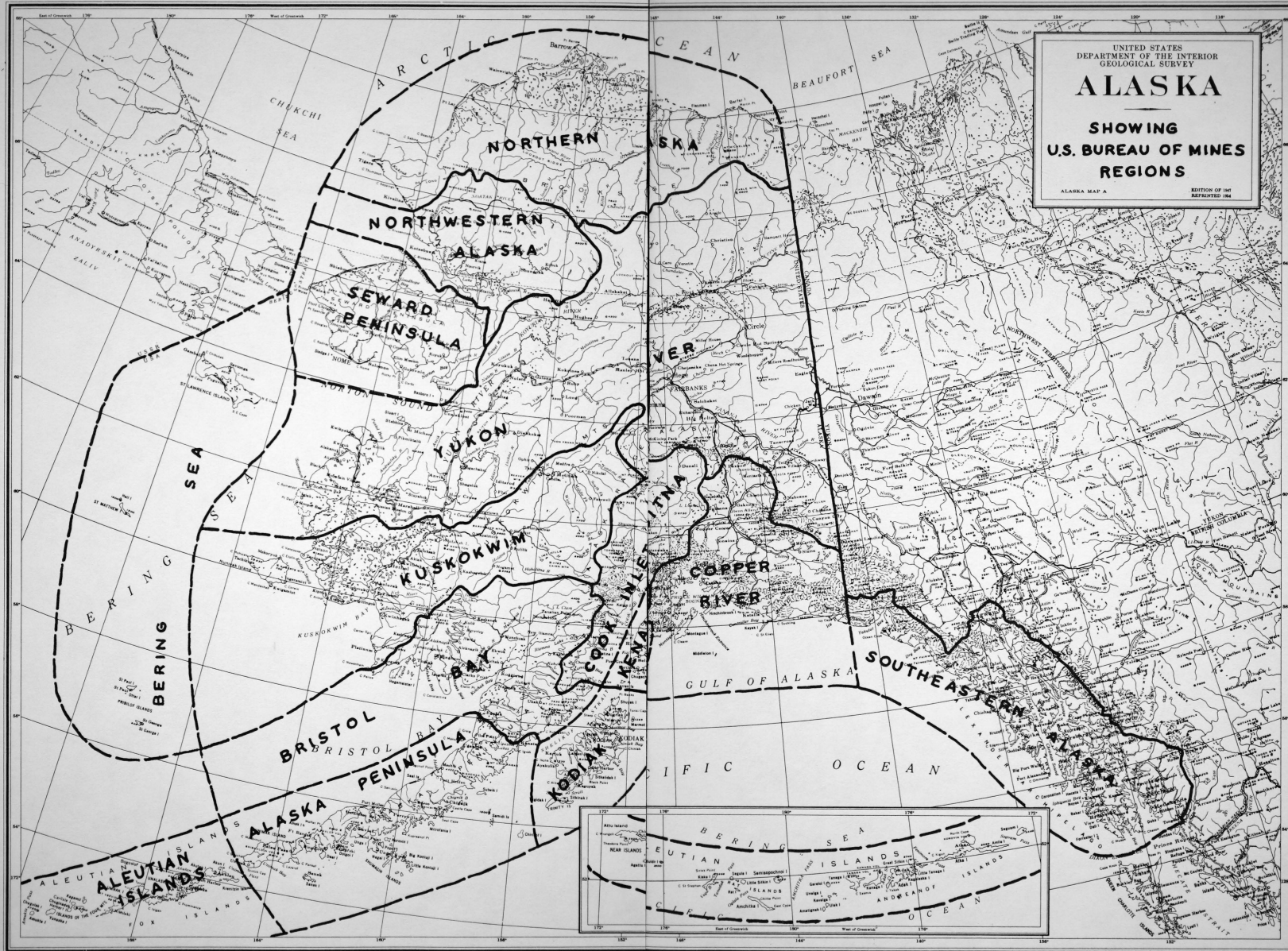
- Weighing gold, 316
- Weight, 374
 - proportional, 256
- Weighted sample, 195
- Welding, blacksmithing, 310
- Western gold provinces, 142
- Wet drill, 300
- Wet ground, 132
- White River copper, 142
- Whitecaps, 129
- Wind, deflation by, 127
 - deposition by, 70, 151
- Windchill, 341, 342, 416
- Wind erosion, 127, 128
- Windgap, 110
- Windlaid sediments, 70
- Windlass, 215, 317
- Wineglass valley, 134
- Winged headland, 131
- Winter frost, 112
- Winze, 192
- Wire lighter, hot, 307
- Wisconsin Glacial age, 98
- Witness stake, 348
- Wolframite, 41, 43, 48, 49, 52, 53, 54, 56, 57, 288
- Wood fires, thawing with, 220
- Wood opal, 34
- Wrenches, drill, 239
- Wrought iron, 309
- Wulfenite, 41, 54, 57, 59

Y

- Yukon River Basin, USBM literature, 403, 431
 - USGS literature, 397, 429
- Yukon sled, 323

Z

- Zirkite, 42
- Zonal arrangement of deposits, 164
- Zone, fault, 79
 - shear, sheated, 148
- Zone of secondary sulfide enrichment, 160



PART II. PROSPECTING

Background: The Prospector, Analysis of Present Status of Mining and Prospecting in Alaska, Brief History, General Prospecting: Definitions, Preliminary to Field Work, Reconnaissance, Lodes: Prospecting, Exploration, Summary of Surface Methods, Underground Openings, Development and Exploitation, Sampling Procedures and Calculating Results, Prospecting and Exploring with Bore Holes, Diamond Drilling: The Diamond Drill, Casing the Diamond Drill Hole, Core Drilling, Placers: General, Open-cutting, Cross-cutting a Creek, Placer Prospect Shafts: Sinking Shafts in Frozen Ground, and in Thawed Ground, Geophysics - Ical, Geochemical, and Mineralogical Prospecting: Methods and Techniques, Auxiliary Techniques: Surveying and Mapping, Drilling Rock for Blasting, Use of Explosives, Blacksmithing, Use of the Pan and Rocker, Handling Gold, How to build various Prospecting Appliances, Camp Life: Transportation, Communication, Shelter, Food, Clothing, Techniques and Equipment, Mining Law: Staking Claims, History, Laws Pertaining to Lodes and Placers, Tunnel Sites, Millsites, Water Rights, Liens, Grubstake Agreements, Patenting, Leasing, Licenses and Taxes, Forms, Geography of Alaska: Subdivisions based on Geography and Geology, Broad Geographical Features, Chief Transportation and Communication Routes, Appendix I. Sources of Information and Aid to Prospectors, Appendix II. Weights, Measures, Sizes, Appendix III. Short Glossary of Alaskan Mining Terms, Bibliography: U. S. Geological Survey, U. S. Bureau of Mines, Bureau of Land Management, University of Alaska, Territorial and State, General, Addendum, Index.

This book is the result of several years of compilation by the author, assisted by a number of people who are acknowledged in the text. The work was in large part subsidized by the University of Alaska, which holds the copyrights.

It is an attempt to gather into one volume the elements of prospecting with special emphasis on Alaska. A glance at the table of contents will show the scope. Many of the subjects discussed in the handbook are applicable to prospecting anywhere, and much of what is said may be found elsewhere. In the treatment of special Alaskan problems, however, it is believed that this book is unique. So far as is known, many processes and techniques are described here for the first time, and an attempt has been made to show how the peculiar historical and climatic conditions have influenced the type of prospector and prospecting that developed in Alaska.

The title marks this as a handbook, and the scope of subjects treated indicates a handbook approach. However the style is not typically "handbook" but has been expanded to provide descriptions detailed enough to allow a person a hundred miles from his nearest neighbor to do what needs to be done simply and safely. It is written in an easy-to-read, not overly-technical manner, informative and refreshing.

The pictures shown on these pages indicate something of the type of illustrations included, and also something of the subjects covered. The book contains 460 large pages with over 100 illustrations, many of which are actual photographs.

The first part of the book is concerned with geology, and the second part with prospecting and mining. Methods for locating minerals, field identification of them, their crystal shapes, and ways to test for the various minerals are given special attention. The handbook also tells how to stake a claim correctly and how to patent it. It explains laws pertaining to lodes, placers, millsites, etc. Interesting phases of prospecting include the art of freighting with dogs, camping out under varying conditions, living off the land, and blacksmithing in a small camp. A very complete bibliography is listed by sections of Alaskan available literature on these geographic divisions is given and space is allowed at the end of each section for future publications and references. The book is carefully cross-indexed with the amateur prospector in mind.

Even if you are not at present ready to prospect in Alaska, you will find much to enjoy in this book. You will learn the meanings of Alaskan colloquialisms such as "cheechako," "outside," and "dry frost." If you are ready to start prospecting, you will find this thoughtful treatise a very useful handbook of things worthwhile.

Since the publication in 1964 of the Handbook for the Alaskan Prospector, it has become a standard work on prospecting in Alaska. The first edition of 2500 volumes was published by the Burnt River Exploration and Development Co. After the book went out of print, arrangements were made with the University of Alaska to publish this second edition which consists of the original text plus an addendum chapter covering developments in the last ten years and brings the bibliography up to date. The index has also been revised to include new material.

